The LPI neutron channel creation

January 12, 2025

Афанасьев С.В.[a,c], Басков В.А.[b], Кутинова О.В.[a,c], Львов А.И.[b], Мильнов Г.Д.[a,c] Сакулин Д.Г.[a,c], Сухов Е.В.[a,c], Устинов Д.В.[a,c], Устинов В.В.[a,c,1]

Afanasiev S.V.[a,c], Baskov V.A.[b], Kutinova O.V.[a,c], L'vov A.I.[b], Milnov G.D.[a,c], Sakulin D.G.[a,c], Sukhov E.V.[a,c], Ustinov D.V[a,c]., Ustinov V.V.[a,c,1]

[a] Joint Institute for Nuclear Research, Dubna, Moscow region, 141980, Russia
[b] P.N. Lebedev Physical of the Russian Academy of Science, Moscow, 119991, Russia
[c] Dubna State University, Dubna, Moscow region, 141982, Russia

Abstract

В Физическом институте им. П.Н. Лебедева РАН (ФИАН) был собран нейтронный канал. Канал необходим для тестирования детекторов спектрометра SCAN-3. Для формирования пучка нейтронов была использована реакция фоторасщепления дейтрона. В статье описывается процесс сборки нейтронного канала и его характеристики.

A channel of labeled neutrons to test the SCAN-3 neutron detectors has been created. The photodisintegration reaction of a deuteron was used to form a neutron beam. The report describes the procedure for creating a neutron channel, the channel parameters, as well as the results obtained during the work.

PACS: 29.40.Mc

Introduction

The SCAN-3 spectrometer represents three-arm setup assembled for detect charged and neutral particles produced in the target by collisions of the Nuclotron beam with target nuclei. The main tasks of the spectrometer is to detect neutrons from the decay of the η-meson nucleus in the $n\pi$- and pn- channels [1]. To reach the required accuracy of neutron energy measurements in energy region 90÷300 MeV, it is necessary to measure the time of flights (TOF) of neutrons with time resolution $\delta t = 400$ ps and spatial resolution $\delta L = 8$ cm simultaneously.

SCAN-3 neutron detector configuration

A 24-items neutron detector divided into 6 independent modules has been developed [2]. The neutron detector of the SCAN-3 spectrometer is located on 3.5 m from interaction point. Each module of the neutron detector composite of four scintillation blocks. It is necessary to achieve the required spatial resolution [3]. Dimensions on

[1] E-mail: ustinov@jinr.ru

each blocks are $800 \times 180 \times 30mm^3$. Readout of signals from blocks is performed by two independent sets of PMTs:
1) set is Hamamatsu R1250 or Philips XP2041 (two PMTs per module);
2) set is PMT-87 or Philips XP2972 (two PMTs per scintillation block).

Preliminary tests of modules were carry out on cosmic rays. The time resolution of the modules has been measured. The measurements have been taken in two sets of PMTs: readout by Hamamatsu R1250 give a result of $250 \div 270$ ps and readout by Philips XP2041 give a result of $770 \div 830$ ps. The time resolution of individual blocks readout by Philips XP2972 give a result is about of $620 \div 650$ ps. This time measurements carried out by 4-channel DRS4 Evaluation Board V3 [4].

LPI neutron channel

A neutron channel (N-channel) is required to tests the neutron detectors in real conditions. A deuteron photodisintegration reaction (1) was used to form neutron beam.

$$\gamma + d = n + p \tag{1}$$

In this reaction, a photon is captured by the deuteron nucleus, followed by a collapse into a proton and a neutron (fig. 1). The energy and momentum of the photon is distributed between the recoil proton and the neutron.

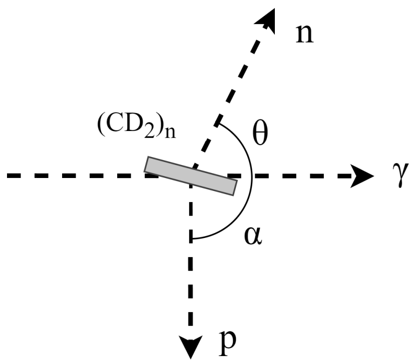

Figure 1: Schematic view of the N-channel

Reaction (1) allows determining the neutrons energy by changing the location angle of the neutron arm and measuring TOF of proton. The dependence of the energy of the detected neutrons on the angle θ of the neutron arm is shown in figure 2. The dependence of the neutron energy on the recoil proton pulse, measured by the time-of-flight method, is shown in the figure 3. The angle θ and TOF of proton makes it possible to determine the neutron energy with good accuracy (Fig. 4).

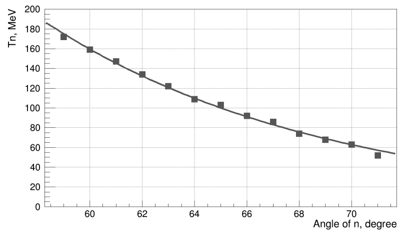

Figure 2: Calculated values of the dependence of the energy of the detected neutrons on the neutron arm angle

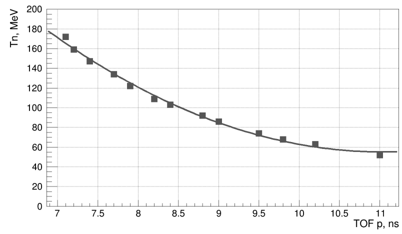

Figure 3: Calculated values of the dependence of the neutron energy on the recoil proton pulse

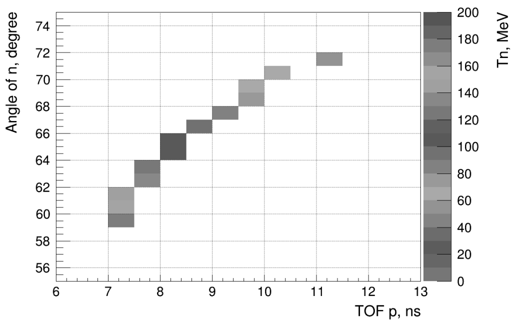

Figure 4: The main view of the facility

Additionally, proton identification is performed by measuring dE/dx ionization losses in a scintillation counter. Measuring ionization losses at the same time as measuring TOF of proton makes it possible to more accurately determine the proton velocity and reconstruct its energy.
For this task, two-arm setup has been created at the P.N. Lebedev Physical Institute of the RAS (LPI) in the Troitsk city [5]. The equipment of N-channel include a neutron arm with the modules under study and a proton arm. The major elements of the setup are:

- a photons beam forming system and transportation system to target (fig. 5);
- a thin(3mm) round deuterated polyethylene target $(CD_2)_n$;
- a fast start trigger counter based on $100 \times 20 \times 3mm^3$ plastic scintillator and two Philips XP2972 PMTs;
- a proton scintillation detector (Recoil arm) located by $\alpha = 90 \pm 2.7$ degrees to the gamma beam direction (fig. 1);
- a neutron detector (N-arm) located by $\theta = 60 \pm 5.5$ degrees to the beam direction (fig. 1).

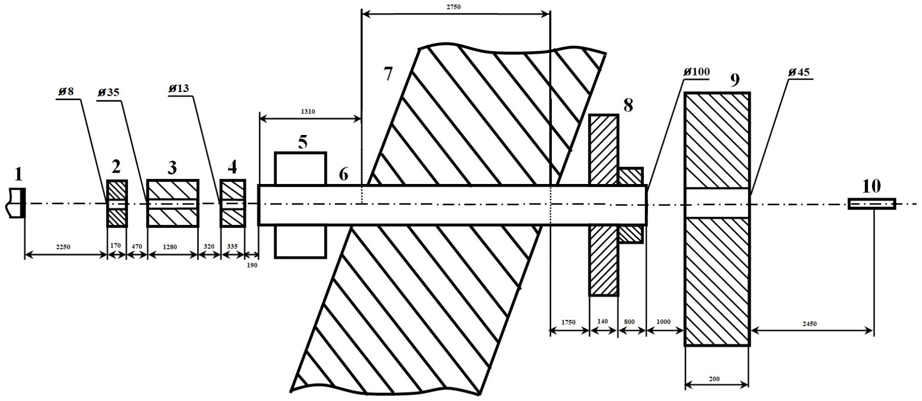

Figure 5: Schematic view of the photon beam formation: 1 –output flange, 2,8 –lead collimators, 3 –water collimator, 4 –iron collimator, 5 –cleaning magnet, 6 –vacuum tube, 7 - wall of the accelerator hall, 9 – lead wall, 10 –target

The target was positioned at an angle of 80 degrees to the beam direction (fig. 1) to increase the efficiency of using the photon beam. This position of the target ensures minimal energy loss of the recoil proton in the target media.
The main view of the experimental setup is shown on figure 6. A lead shields to protect detectors from the background are used.

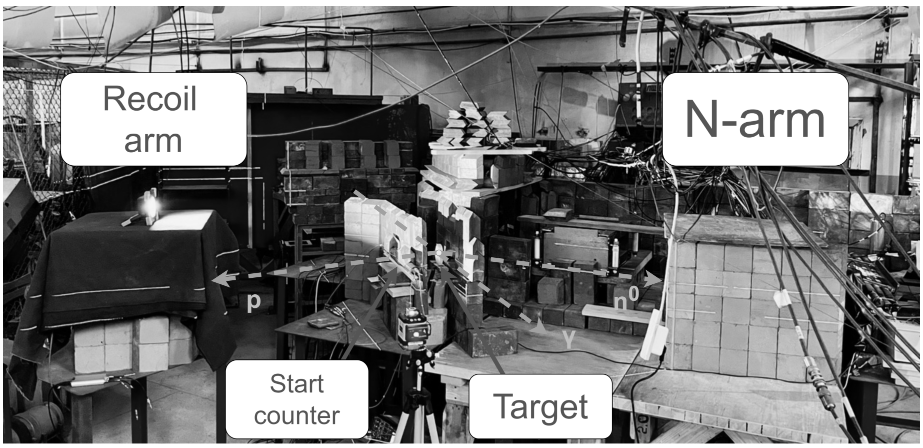

Figure 6: The main view of the facility

The photon beam was forming by means interaction of electrons beam onto a tungsten target with a thickness of $0.22X_0$. The energy of the primary electrons is $500MeV$ at an intensity is $2 \cdot 10^{12}$ electrons/s. This allows to get intensity of photons is $2 \cdot 10^9$ photons/s and gives neutron flux is about 1 neutron/s.
The neutron channel was tested in the middle of 2024. The registered signals from the detectors of the setup are shown in figure 7. The upper two waveforms correspond to the signals from the trigger counter. The lower two waveforms correspond to the

signals of the neutron and proton detectors, respectively.

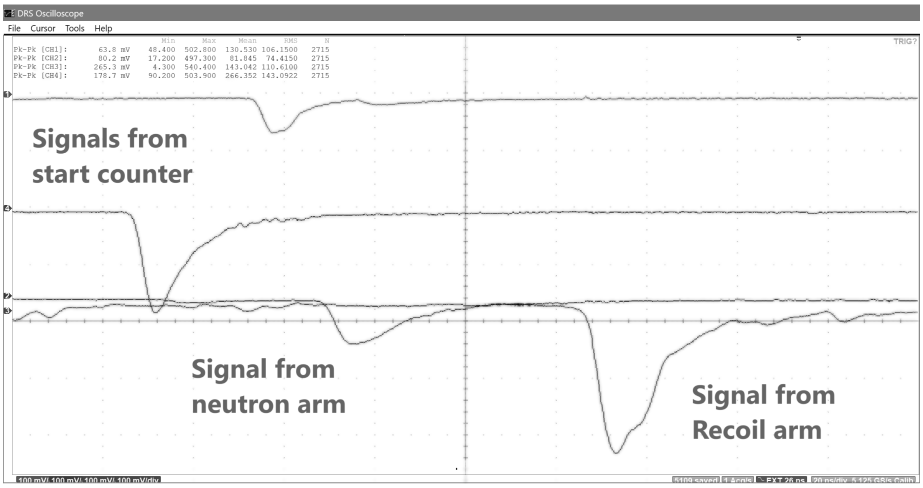

Figure 7: The sample of registered signals from the detectors of the N-channel

Conclusion

A setup for measuring detectors on neutron beam has been assembled. The first measurements were carried out at setup. The fourfold coincidence of the detector signals indicates the decay of the deuteron nucleus in the target. It is planned to provide full complex studies of the neutron detectors in 2025 on the assembled neutron channel at LPI.

References

[1] *S.V. Afanasev et al. Three-Arm Spectrometer SCAN-3 on Nuclotron Internal Targets. Physics of Particles and Nuclei, 2024, Vol. 55, No. 4, pp. 1119-1123.*

[2] *S.V. Afanasev et al. Upgrade of the SCAN-3 Spectrometer at Nuclotron. Physics of Particles and Nuclei Letters, 2023, Vol. 20, No. 5, pp. 1232–1235.*

[3] *Ustinov V.V. et al. Development of the multilayer neutron detectors for the SCAN-3 spectrometer. Proceedings of MIPT. 2021. V. 13, N 3. P. 122–132.*

[4] *DRS Evolution Board*URL:https://www.psi.ch/en/ltp-muon-physics/evaluation-board

[5] *LPI Troitsk science park.*URL: https://sites.lebedev.ru/ru/scipark/