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STUDY OF AXIAL ANISOTROPY OF NEUTRON YIELD IN THE RECONSTRUCTION OF NEUTRON ENERGY SPECTRA IN D-D REACTION

K. Rezac[1], D. Klir[1], J. Kravarik[1], P. Kubes[1],
I. Ivanova-Stanik[2], M. Scholz[2], M. Paduch[2], K. Tomaszewski[2], B. Bienkowska[2]
[1]*FEE CTU in Prague, Technicka 2, 166 27 Prague 6, Czech Republic*
[2]*IPPLM Warsaw, Hery 23, 00-908 Warsaw, Poland*

1. INTRODUCTION

The neutron diagnostics is very important for fusion plasma analyzes. By using the diagnostic methods we can identify many parameters of fusion plasma. The neutron spectroscopy diagnostics is a well-established diagnostics for short-lived plasma such as plasma foci and Z-pinches. The energy spectrum of neutrons produced in fusion plasmas provides information of the production mechanisms of the emitted neutrons, ion temperature, and the energy distributions of the reacting ions.

The reconstruction is based on the kind of the time-of-flight methods which determine the energy (velocity) spectrum of the particles from the particle flux shape evolution during free propagation. The experiment consists of recording of signals in a chain of detectors placed at various distances from the particle source. Then the energy spectra are reconstructed from time-resolved signals which are recorded by several detectors in one direction at different distances. There are several theoretical approaches for the development of algorithms, such as reconstruction by Laplace transformation [1], reconstruction by convolution and back-projection, Monte Carlo reconstruction method [2], maximum entropy method, genetic algorithm etc. One of these techniques (namely a Monte Carlo, which is fully described in [2, 3]) was used.

The basic formulation of the problem as well as numerical test results indicate that the methods could give better results when detectors in the opposite direction are also included (all quadrants of reconstruction domain are used). If we want to involve both directions of neutron detection, we must know the relation between the neutrons which are emitted in one direction and the opposite direction. This relation includes the transformation of the neutron energies and the anisotropy in cross sections.

2. THEORETICAL BACKGROUND

2.1. Energy of emitted neutrons in D-D reaction

In order to find the neutron energy transformation we used the kinematics of the binary fusion system, which describes collision of a particle with a stationary target. The neutron energy in laboratory system (LS) from the D-D reaction is mentioned in [4]. Specifically neutron energy for angle between colliding deuteron and emitted neutron 0° and 180° is derived in [3].

2.2. Differential cross section for D-D reaction

Because a different number of neutrons could be emitted in one direction with respect of the other direction, we have recently included the anisotropy of differential cross section (by extension, anisotropy of neutron yields) into our calculations. The process to find the anisotropy of neutron yields is the following.

The differential cross section $d\sigma/d\Omega$ in the centre-of-mass system (CMS) can be expanded in Legendre polynomials P_n as [4]

$$\frac{d\sigma}{d\Omega} = \sigma_0 (A_0 + A_2 P_2(\cos\vartheta) + A_4 P_4(\cos\vartheta) + ...), \tag{1.1}$$

where ϑ is the emission angle in the CMS and σ_0 is the differential cross section for $\vartheta = 0^\circ$. The expansion coefficients A_n was taken from [5]. The differential cross section $d\sigma/d\Omega_{LS}$ in the LS can be written as

$$\frac{d\sigma}{d\Omega_{LS}} = \frac{d\sigma}{d\Omega} \cdot \frac{\left(1 + 2\zeta\cos(\vartheta) + \zeta^2\right)^{3/2}}{1 + \zeta\cos(\vartheta)}, \tag{1.2}$$

where ζ is defined as $\zeta = V_{CMS}/v_n$, where V_{CMS} is the CMS velocity of the colliding particles and v_n is the neutron velocity in the CMS.

2.3. Axial anisotropy of neutron yield

The axial anisotropy of neutron yield was calculated using the equation (1.2). The ratio (i.e. anisotropy) between differential cross-section for $\vartheta_{LS} = 0^\circ$ and $\vartheta_{LS} = 180^\circ$ as a function of deuteron energy for D-D reaction is shown on the Fig. 1. This anisotropy was used in our reconstruction of the neutron energy spectra from axial neutron detectors. The neutron detector signals were normalized according to anisotropy before starting of the calculation.

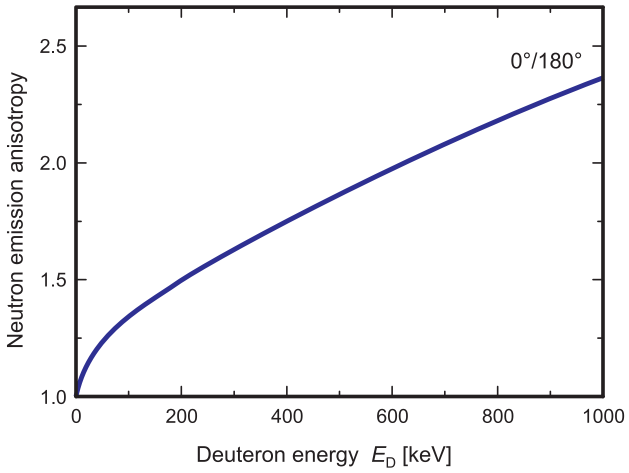

Fig. 1: The ratio between differential cross-section for $\vartheta_{LS} = 0^\circ$ and $\vartheta_{LS} = 180^\circ$ as a function of deuteron energy for D-D reaction. The angle ϑ_{LS} is the angle in the LS between fast deuteron and an emitted neutron.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The Monte Carlo reconstruction method, which calculates neutron energy spectra from neutron signal detectors placed in the both directions from neutron source (0° and 180° in our case – videlicet downstream and upstream directions), was used in the processing of data from experiments in the PF 1000 facility. This device is located at the Institute of Plasma Physics and Laser Microfusion (IPPLM) in Warsaw. The device has horizontal axis, which is important for time-resolved neutron diagnostics. The experiments were performed with the electrical energy of (600 ÷ 650) kJ, voltage of 27 kV, and current maximum of 2 MA. The entire chamber was filled with the deuterium gas (pressure 400 Pa). The neutron yield is usually up to 10^{11} neutrons per shot. Neutron diagnostics contained chain of nine axial detectors (experiments in October 2006). The detectors were situated downstream (at distances of 7 m, 16 m, 58 m, and 84 m) and upstream (at distances of –7 m, –16 m, –30 m, –58 m , and –84 m).

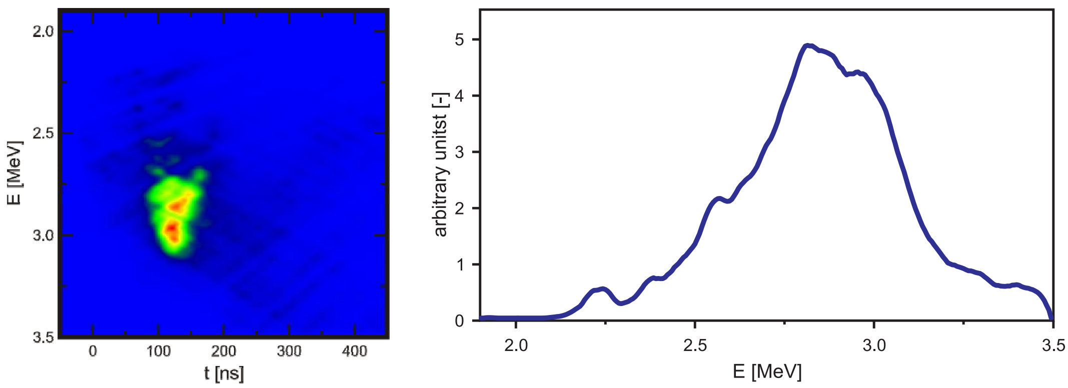

Fig. 2: Reconstructed time resolved energy spectrum (shot #6540, 24th October 2006) in downstream direction (left). The time integrated neutron energy spectra (right).

The result of the application of the improvement Monte Carlo reconstruction method is shown in figure 2 for shot #6540. The time resolved reconstructed energy spectrum displays most neutrons with the energy of (2.65 ÷ 3.05) MeV. These neutrons are emitted mainly between 90 and 160 ns. The anisotropy (downstream neutron yield / upstream neutron yield) is approximately 1.26.

5. CONCLUSION

The problem of the reconstruction of the time dependent neutron energy spectra from D-D reaction was discussed in this paper. We described the improvement of the reconstruction methods which is based on the inclusion of the neutron detectors placed in the opposite direction. The axial anisotropy of neutron yields was included during both direction calculations. Further the application of the Monte Carlo method for the reconstruction of energy spectra was shown. Namely, shot #6540 from experiments in the PF 1000 facility was presented. The reconstructed energy spectrum displays most neutrons with the energy of (2.65 ÷ 3.05) MeV. These neutrons are emitted mainly between 90 and 160 ns. On the basis of our calculation including the axial anisotropy, we can enounce that the results do not differ qualitatively to previous calculations [3, 6] in which the axial anisotropy was not included.

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