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MONTE CARLO METHOD FOR PLASMA-FOCUS NEUTRON SPECTRUM RECOVERY -A NEW APPROACH THAT INVOLVES ACCELERATED IONS DISTRIBUTION

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Abstract

New method of neutron spectrum recovery described in the paper involves accelerated deuterons (that produce neutrons in the DD reactions) and allows to get neutron spectrum in any direction from computed time-velocity-angle characteristics of deuterons. Time of flight (TOF) signals registered at various distances and directions can be used in the deconvolution process that makes information involved in the recovery process (Monte-Carlo simulation) more complete than in a one-directional case. In the paper results of standard tests of the proposed method are presented demonstrating its capability to recover neutron spectrum from TOF signals.

Introduction

For various possible application of Plasma-Focus as an intense neutron source a precise knowledge of the neutron spectra is of great importance. This knowledge is also necessary to explain a mechanism or mechanisms of neutron generation from the Plasma-Focus that lead to unexpectedly high neutron yield observed. One of the methods used for neutron spectra measurements was the time-of-flight method known in nuclear physics. The TOF is based on the unique relation between the particle energy and experimentally measurable time, which is required by particle to travel in the free motion a given distance. Unfortunately for a neutron source characterized by relatively long emission time (50 to 500ns) this method is not precise enough. As it is well known, the formula for relative error of the particle spectrum measurement has the form: $\Delta E / E = 2\Delta T / \tau$, where ΔT is an emission duration and $\tau = x / v$ is the average particle time of flight from the source to the detector. For 2.45 MeV neutrons emitted in a 300ns pulse and the distance about 80 m acceptable from the point of view of the TOF signal detection the $\Delta E / E$ is of the order of 15% (more than 300 keV).

New approach, in which the neutron pulse are recorded in an extended TOF arrangement (a number of detectors placed at various optimized distance from the source) was developed and presented in [1, 2]. From neutron pulses recorded a neutron spectrum was recovered using a special mathematical procedures and this method is similar to the one widely used in the medical tomography. I. Teseanu [3] tested several methods of the reconstruction of neutron energy spectrum and found that best results could be achieved using the analog Monte Carlo (MC) reconstruction technique. In [4] they presented the results of the application of the MC reconstruction method for determining of the time resolved energy spectrum of fusion neutrons emitted by the plasma focus generator (SPEED 2). The authors in ref. [5], reported that better results could be achieved by using detectors placed on both sides of the pinch (down-stream and up-stream). This idea has one serious limitation namely an intrinsic assumption that deuterons are moving only along the axis. From previous measurements of the neutron spectra done on other PF devices it was found that the end-on spectrum is shifted to 2.7-2.8 MeV while the side-on one is well centered around 2.5 MeV but with high FMWH of the order of 400 keV. Such a spectra can be explained practically only by taking into account accelerated deuterons moving at various angles in respect to the axis.

In the paper we propose a modified approach to the MC methods discussed above. Instead of 2D recovery space (time-neutron energy) we are working in 3D space namely time – deuteron velocity vector (time, velocity module and angle in cylindrical co-ordinates). It allows to use the TOF signals (from scintillator-photomultipler probes) placed not only at various distances from the source but also at different angles in respect to the PF axis. Such approach has, in our opinion, at least two advantages:

- involvement into the recovery procedure of the strongly nonlinear relations between deuteron motion characteristics and resulting neutron energy and cross section should improve a selecting capabilities of the MC method,
- from the time-deuteron velocity distribution one can get immediately spectra of neutrons emitted in any direction.

The method

We consider the case, where the fast deuteron with energy E_d, moving at an angles α and Φ with respect to the axis, collides with a deuteron at rest (Fig. 1.). Suppose that the high energy neutron is produced by the D-D fusion reaction and it is emitted with velocity $\mathbf{U_n^{CM}}$ and angle Ψ_n in the center-of-mass system and with velocity $\mathbf{U_n^{l}}$ and angle Ψ_L in the laboratory system. (the angle Ψ_L corresponds to the direction of a detector). The relation between angle Ψ_n and Ψ_L is: $\cos\psi_n = -\rho\sin^2\psi_L + \cos\psi_L\sqrt{1-\rho^2\sin^2\psi_L}$,where $\rho = V_d/U_n^{CM}$. This angle Ψ_L can be related to the incident deuteron angle α. For three different direction of the detection (0^o, 90^o, 180^o) we have, respectively: $\cos\Psi_L=\cos\alpha$, $\cos\Psi_L= \sin\alpha\cos\Phi$, $\cos\Psi_L =-\cos\alpha$, where Φ is the azimuth angle between the axial planes and emitted neutron

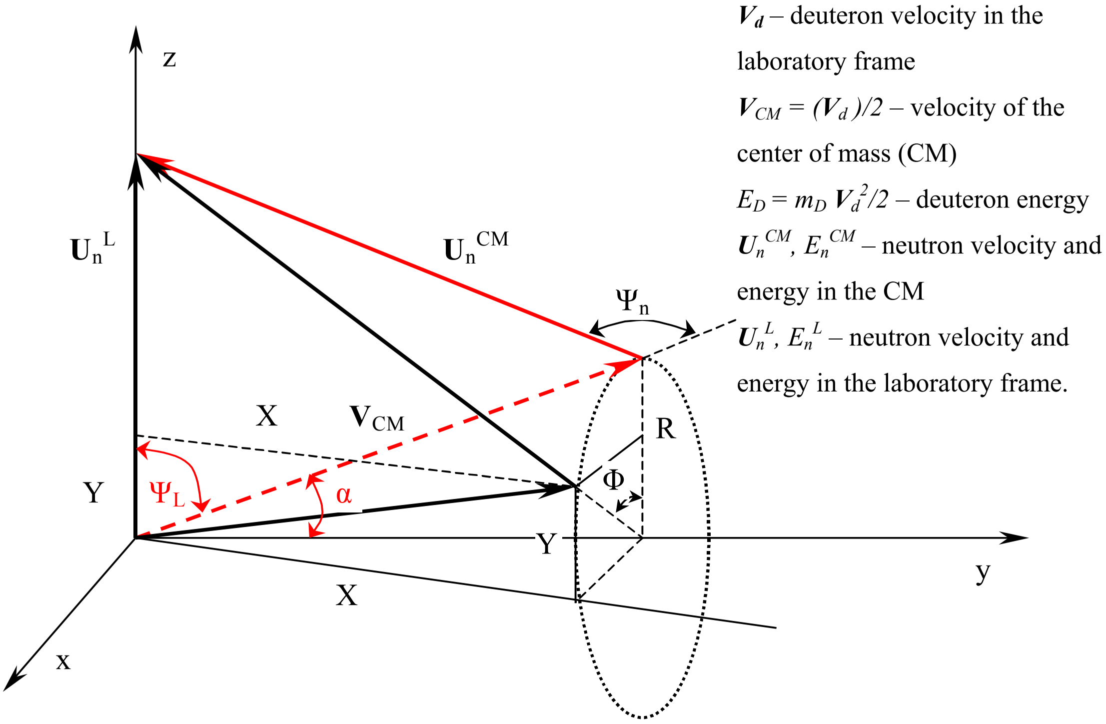

Fig.1. Vectors diagrams for deuteron fusion collisions

The differential cross section for D-D reaction (one deuteron in rest) in the laboratory frame has the form:

$$\frac{d\sigma}{d\Omega_l} = \frac{\sigma_T(E_d)}{4\pi}\left[\frac{1 + A(E_d)\cos^2\psi_n + B(E_d)\cos^4\psi_n}{1 + \frac{A(E_d)}{3} + \frac{B(E_d)}{5}}\right]\frac{\left(1 + 2\rho\cos\psi_n + \rho^2\right)^{3/2}}{\left(1 + \rho\cos\psi_n\right)}$$

where σ_T is the total D-D cross section for neutron production [6] and the coefficients A and B were taken from [7].

Reconstruction algorithm

The reconstruction algorithm consists of the following steps:

- Step I -sampling of events by uniform random generator for deuterons in the plane (t, E_d^{CM}, α, Φ) at the source position (0, 0, 0). We calculate neutron energy for 3 different direction (0°, 90°, 180°) and times of arrival of the neutrons at all detector positions. Then the algorithm tests if the event is detected by all detectors. When the test is passed, the event is accepted (one is added to the point corresponding to the event in the reconstruction plane) and values proportional to the number of neutrons generated by the event (cross section) are subtracted from all signals registered.
- Step II and next steps: - sampling of events is repeated using probability function proportional to the result of the previous step. This kind of recurrence may be continued till the saturation of the number of accepted events improving the quality of the reconstruction.

Numerical tests and discussion

To demonstrate the capability of the method in reconstruction of deuteron distribution a simple test has been performed. An artificial deuteron distribution has been assumed having the following form: $F_d = \sum_1^3 \varepsilon_i(E_d) * \zeta_i(t) * \theta_i(\alpha)$ where: $\varepsilon(E_d), \zeta(t)$ are the Gauss functions $G(x) = A\exp(-(x-\bar{x})^2/\Delta x^2)$ with the parameters given in the table below:

i	A	$\overline{E}_d[keV]$	$\Delta E_d[keV]$	$\bar{t}[ns]$	$\Delta t[ns]$
1	1	80	20	120	20
2	1	150	20	170	20
3	1	80	20	220	20

$$\theta(\alpha) = \begin{cases} 0 & for \quad 0 < \alpha \le 10^0 \\ 1 & for \quad 10 < \alpha \le 20^0 \\ 0 & for \quad 20^0 < \alpha \le 180^0 \end{cases}$$

Using the above distribution of deuterons the neutron signals registered by ten detectors placed at distances: 2.84m, 10m, 48.3m, 84.29m and angles 0^o,90^o and 180^o (ten in total) have been computed and than used as an input to the code.

Preliminary tests of the two, first steps of the procedure are presented on Fig. 2.

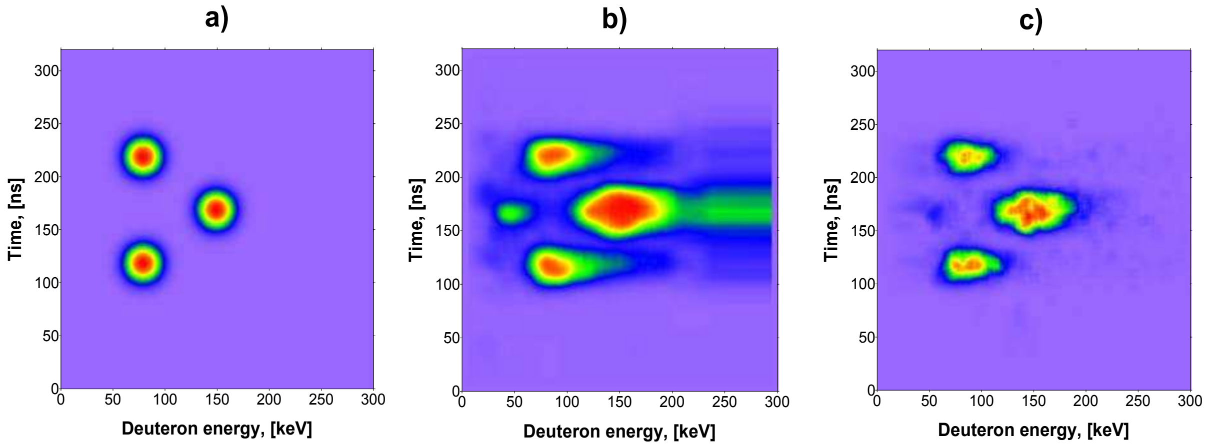

Fig.2. The spectrum recovery process: a) assumed distribution of deuterons b) and c) results of the recovery process after first and second step of the procedure.

It can be seen, comparing figures a) and c) that the results of the initial distribution recovery are very promising. After two steps maxima of the distribution have been localized with good precision and number of artificial points in the distribution is quite small.

The code still needs additional improvements and testing. The spectrum recovery procedure will be checked and analyzed step by step in view of acceleration of the computational process and enhancement of its accuracy.

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