Investigation of low energy p-wave resonances in $^{93}Nb(n,\gamma)$ reaction

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There is a deficiency of information about spins, widths , mixing parameters of p-wave neutron resonances, especially for weak low-energy p-wave resonances of nuclei with A>100. And experimental study of P-even asymmetry in (n,γ)- reactions near p-wave resonances promotes obtaining of new data.

Experimental observation of P-odd spatial parity violation in neutron resonances

Experimental study of the dependence of the total neutron cross sections on the neutron helicity near low-lying p-wave resonances began at the IBR-30 reactor of FLNP, JINR (**Dubna**) in 80's:

[***V.P. Alfimenkov, S.B. Borzakov, Vo Van Thuan, Yu.D. Mareev, L.B. Pikelner, A.S. Khrykin*** *and* ***E.I. Sharapov****, Parity nonconservation in neutron resonances, Nuclear Physics, A 398, 1983, 93–106*]

Knowing the parameters of mixing s- and p-wave resonances, from the measured ratio $\mathcal{P}$ (where $\sigma^+$and σ^- are the total cross sections of neutron of opposite polarization), the weak interaction matrix element W_{sp} can be calculated, which violates spatial parity in the interaction of the neutron with the nucleus:

$$\mathcal{P} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{2W_{sp}}{E_p - E_s}\sqrt{\frac{\Gamma_n^s}{\Gamma_n^p}}\sqrt{\frac{\Gamma_n^p(j_n = 1/2)}{\Gamma_n^p}}$$

Experimental measuring of P-even angular correlations of γ-quanta in (n,γ) reactions

Partial neutron widths of p-resonances, $\Gamma_n^p(j_n = 1/2)$ and $\Gamma_n^p(j_n = 3/2)$, can be obtained studying

- right-left asymmetry of γ-quanta emission in radiative capture of polarized neutron
- forward-backward asymmetry of emission of direct transition γ-quanta
- angular anisotropy of p-component of the (n, γ)-reaction cross section

Nucleus	p-resonance	$\Gamma_{n,1/2}^p/\Gamma_n^p$ anisotropy
$^{93}_{41}\mathrm{Nb}$	35.8 eV	0.70±0.08 (BNL)
	42.2 eV	0.27±0.17 (BNL)
	94.3 eV	0.84±0.13 (BNL)

Angular correlations in (n,γ) reaction

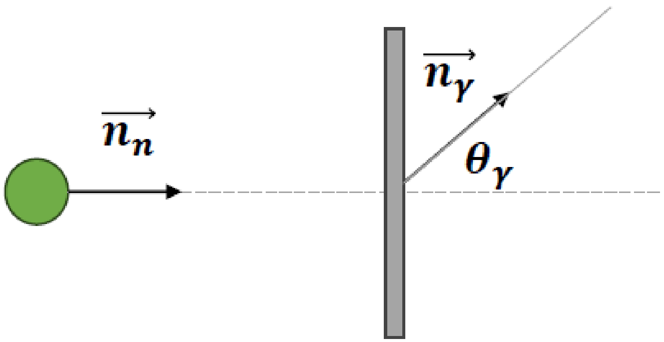
When unpolarized nucleus captures unpolarized neutrons of the low energies which allows to limit their orbital moments by a condition $l \le 2$, the Legendre polynomial expansion of the differential cross section of radiative capture has a simple form:

$$\frac{d\sigma(\vec{n}_\gamma,\lambda)}{d\Omega} = \frac{1}{2}\left\{a_0 + a_1(\vec{n}_n\vec{n}_\gamma) + a_2\left[(\vec{n}_n\vec{n}_\gamma)^2 - \frac{1}{3}\right]\right\} = \frac{1}{2}\left\{a_0 + a_1 \cos\theta_\gamma + a_2\left[\cos\theta_\gamma{}^2 - \frac{1}{3}\right]\right\},$$

where the Legendre polynomials are $P_1(cos\theta) = cos\theta$ and $P_2(cos\theta) = (3cos^2\theta - 1)/2$,
$\lambda -$ de Broglie wave length, a_0, a_1 and a_2 are functions of reaction amplitudes.

$$a_0 = |U_1|^2 + |U_2|^2;\ a_1 = Re(U_1U_2^*)(-2x + 1.414y);\ a_2 = |U_2|^2(-1.061\cdot 2xy - 0.75y^2);$$

where $x = \sqrt{\frac{\Gamma^n_{p,j=1/2}}{\Gamma^n_p}}$, $y = \sqrt{\frac{\Gamma^n_{p,j=3/2}}{\Gamma^n_p}}$, $x^2 + y^2 = 1.$

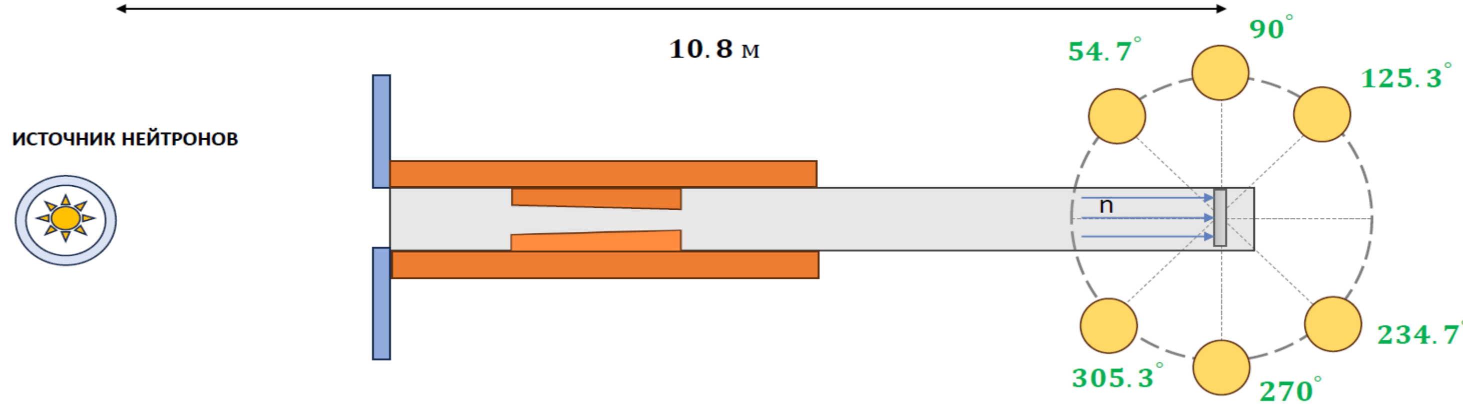


The forward-backward asymmetry effect can be written as:

$$\varepsilon^{f-b}(\theta) = \frac{\sigma(\theta)-\sigma(\pi-\theta)}{\sigma(\theta)+\sigma(\pi-\theta)} = \frac{a_1 cos\theta}{a_0+a_2P_2(cos\theta)}.$$

Measuring the forward-backward asymmetry of gammas of radiative neutron capture

In order to obtain $\Gamma_{n1/2}$ and $\Gamma_{n3/2}$ partial widths, measurements of forward-backward asymmetry of γ-quanta from ^{93}Nb(n,γ) reaction in the energy region of incident neutrons near low-energy p-wave resonances are carried out at 11-m flight-path of the IREN facility (FLNP, JINR).



IREN facility characteristics

Average electron energy: 110±5 MeV
Pulse frequency: 50Hz
Average current: 10.8 µA

Thermal and resonance neutron fluxes

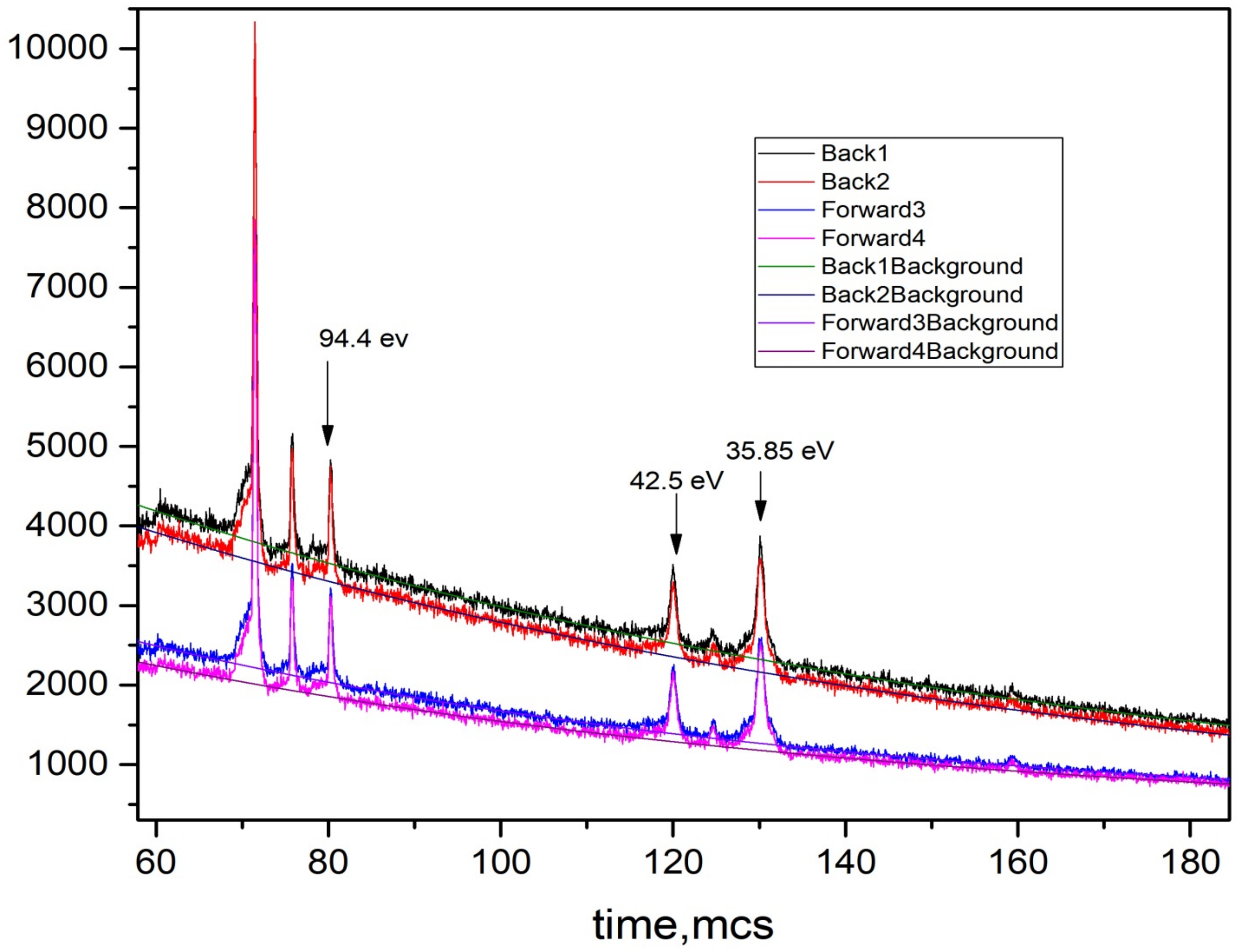
were measured by means of activation of gold foils

1. using pairs of monitors in cadmium and without protection
2. and with a gold screen.

$$F_{th} = 1.5 \cdot 10^4 \ n/cm^2 \cdot s$$
$$F_{res} = 6.0 \cdot 10^3 \ n/cm^2 \cdot s$$

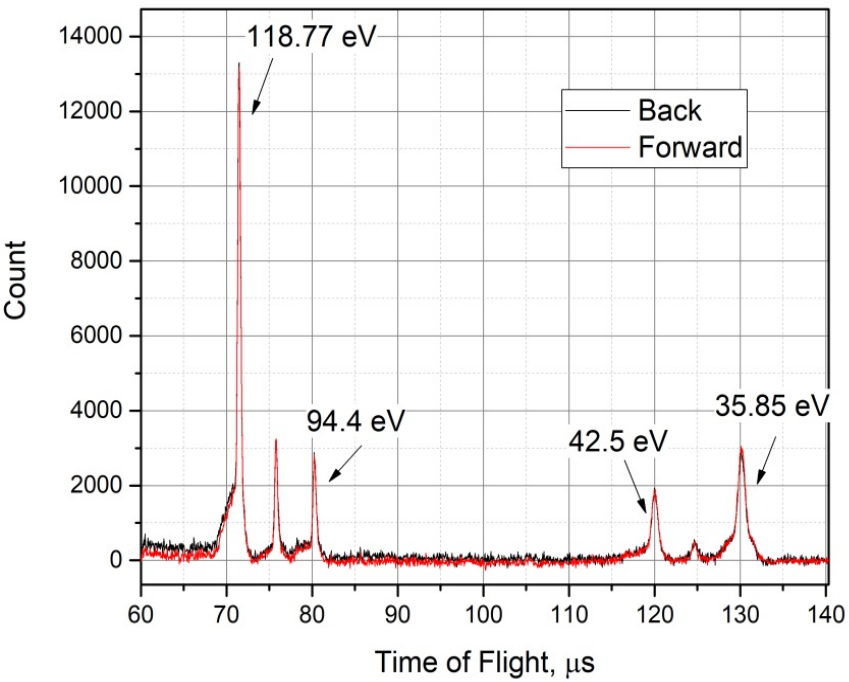
For γ-quanta recording BGO ($Bi_4Ge_3O_{12}$) detectors were used (sensitive element – cylinder of bismuth germanate with Ø=7.75 cm and a height of 6.5 cm).
The experimental data were collected using the “DSR” digitizer.

Forward-backward measurement of gammas near p-wave resonances of 94-Nb

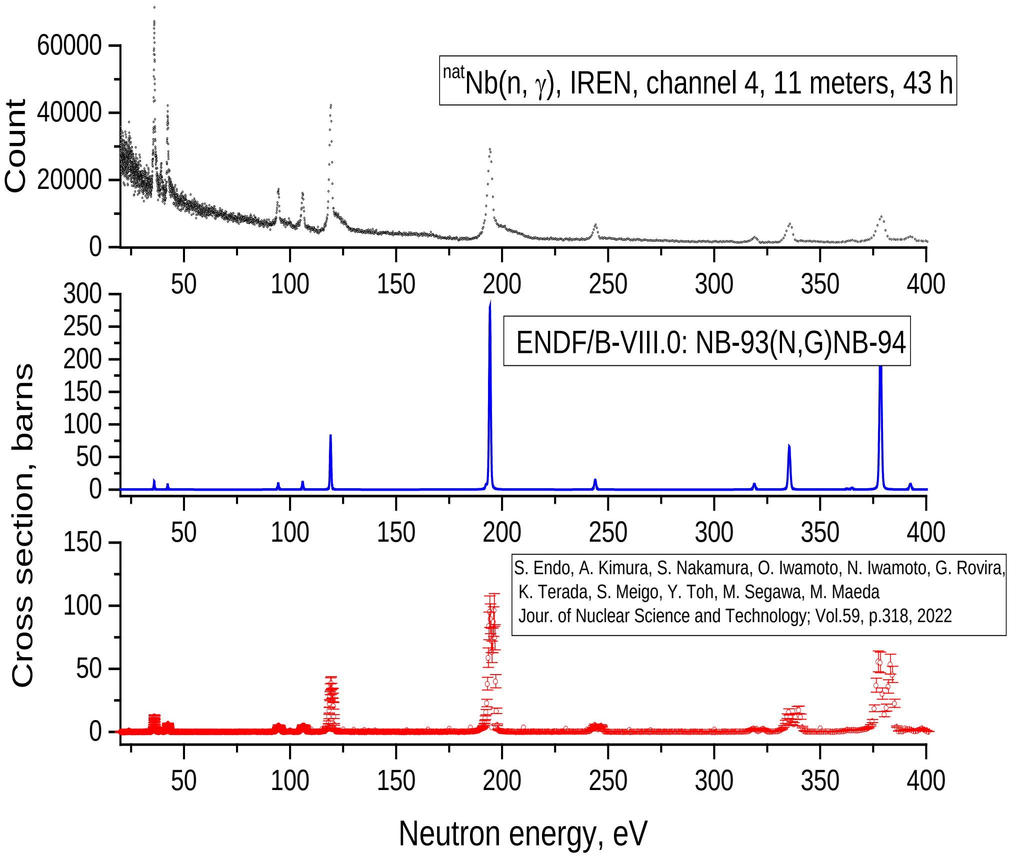


Number of gammas of radiative capture at 4×4 cm plate of 93-Nb with thickness of 4 mm recorded by 2 forward and 2 backward detectors during 43 hours. The backgrounds were fitted after normalization on the square of strong 193.6 eV s-resonance.

Forward-backward measurement of gammas near p-wave resonances of 94-Nb

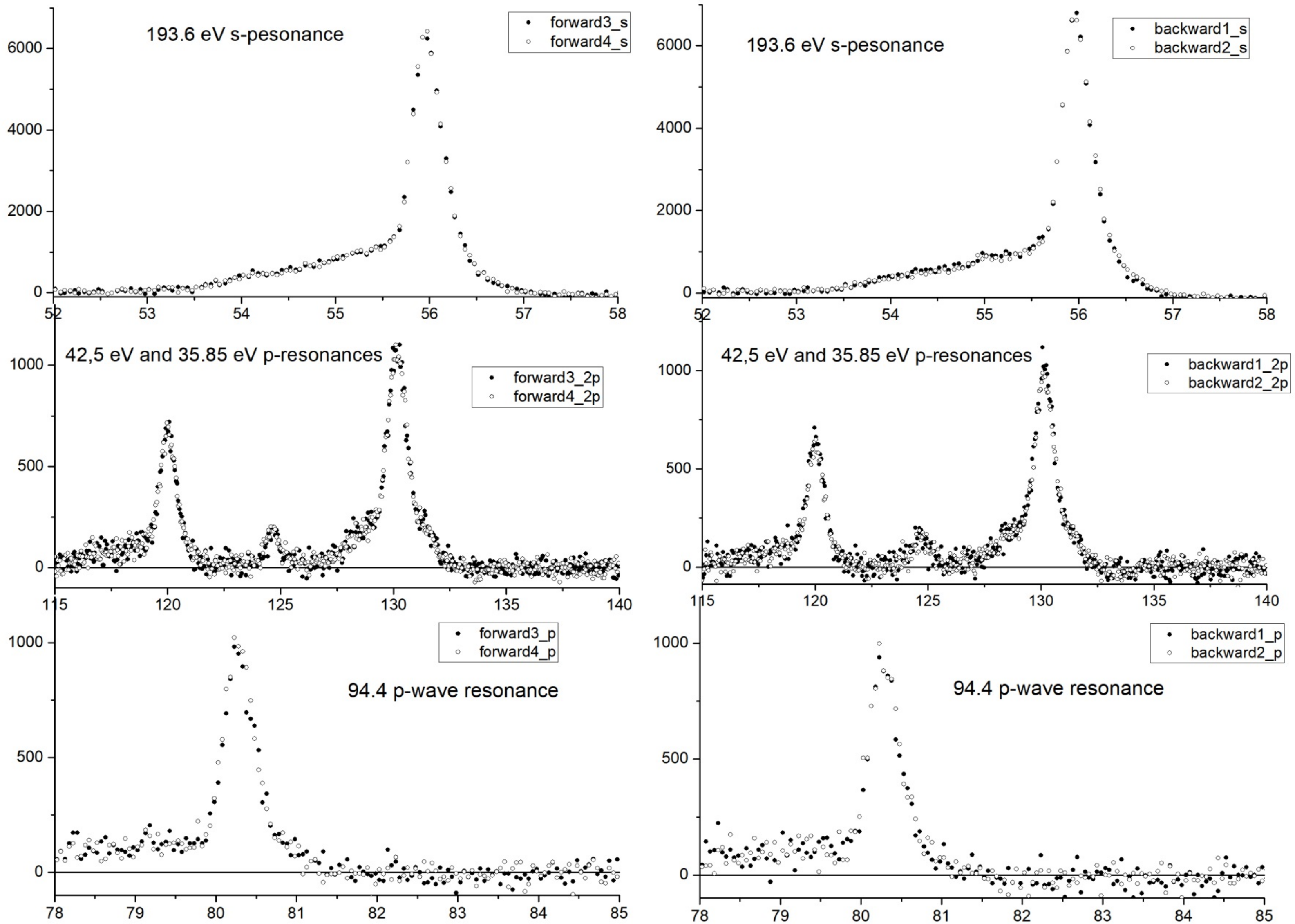


Counts of gammas summarized for 2 forward and 2 backward detectors after background extraction



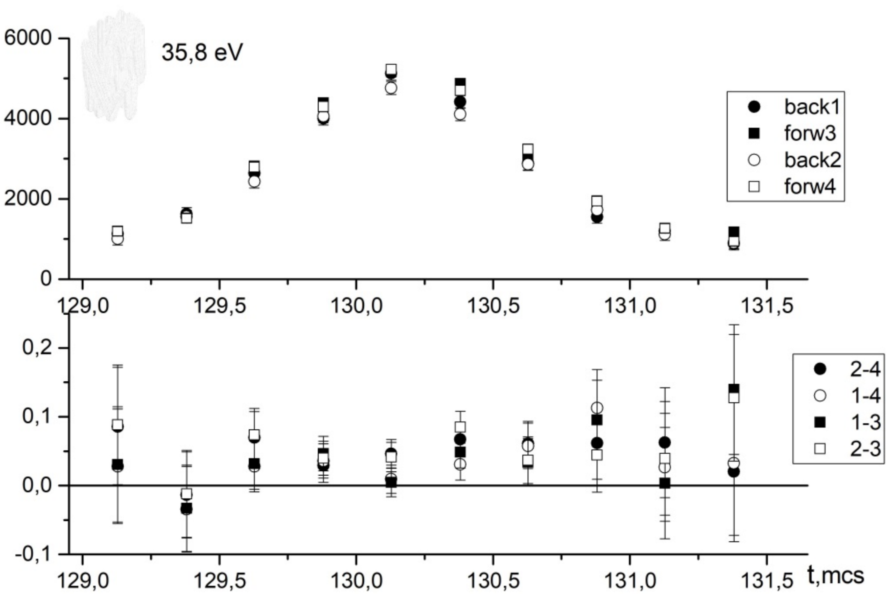
Verification of locations of the investigated p-wave resonances

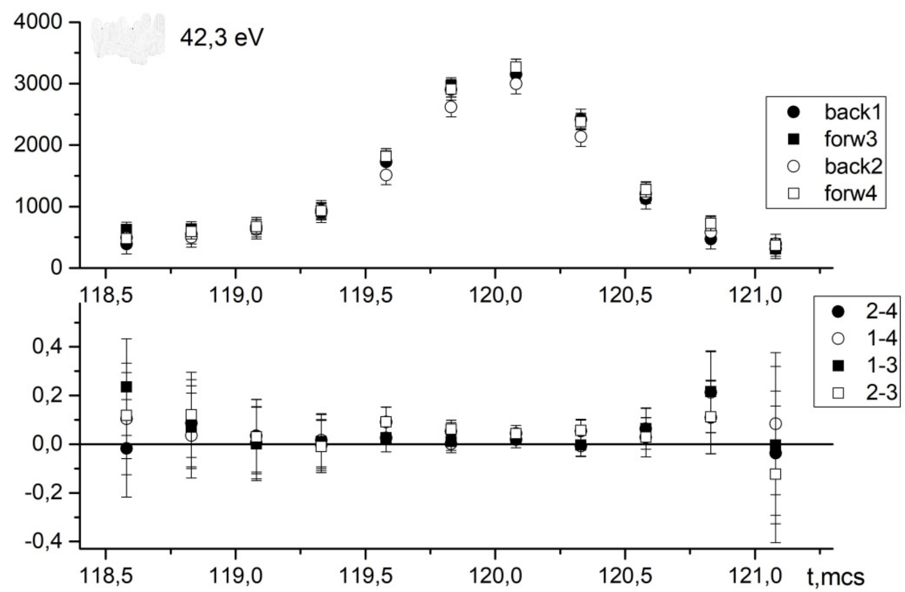
Forward-backward measurement of gammas near p-wave resonances of 94-Nb

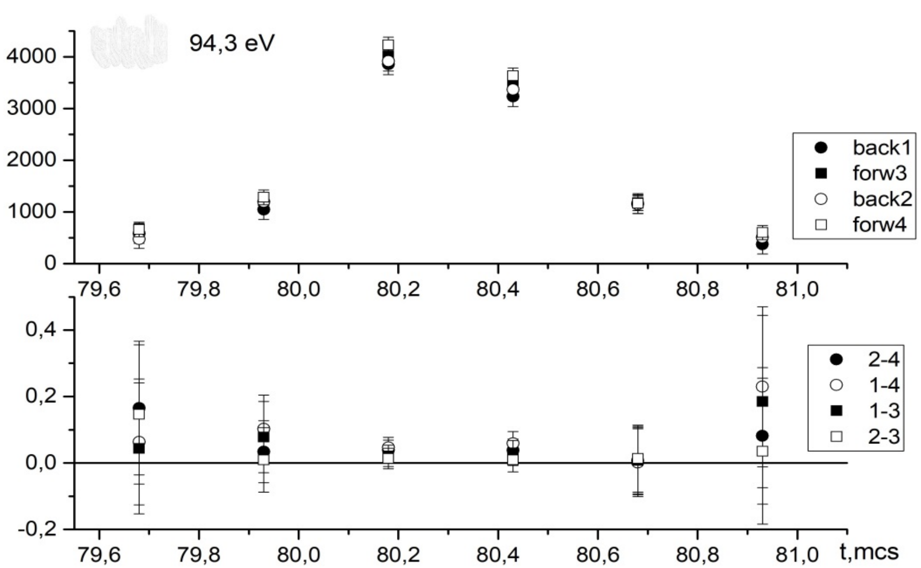


Counts of gammas after measured spectra normalizing on biggest square of 193.6 eV s-resonance and background subtracting for backward detectors (from the left) and for forward detectors (from the right)

Results of measurements of forward-backward γ-detection asymmetry for 35.8, 42.3 and 94.3 eV p-wave resonances







Counts of gammas (summarized over 5 channels) in the resonances for 2 forward and 2 backward detectors taking into account uncertainties of subtracted background (top pictures) and the counts ratios, eff(E), for each pair of the detectors (bottom pictures)

$$\mathrm{eff}(E) = \frac{N_{forw}(E) - N_{backw}(E)}{N_{forw}(E) + N_{bacw}(E)}$$

We express our gratitude to the team of the resonance neutron source IREN

Thank you for your attention!