Monte-Carlo Evaluations of Low-Energy Neutron Radiative Capture in ^{93}Nb-Targets and γ-Quanta Forward-Backward Asymmetry Caused by Geometry and Kinematics

Kuznetsov V.L.[1,2], Mitsyna L.V.[1], Rebrova N.V.[1], Sedyshev P.V.[1]

[1]Frank Laboratory of Neutron Physics, JINR, Dubna
[2]Laboratory of Neutron Research, INR RAS, Troitsk

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 10-m flight-path of the IREN facility (FLNP, JINR) in order to open up a possibility of obtaining $\Gamma_{n1/2}$ and $\Gamma_{n3/2}$ partial widths.

To evaluate of inevitable distortion of the required spatial γ-anisotropy by the asymmetry of γ-quanta detection caused by kinematics and geometry, Monte-Carlo calculations were performed with ^{93}Nb-targets of different thicknesses.

Calculations of neutron capture in the targets

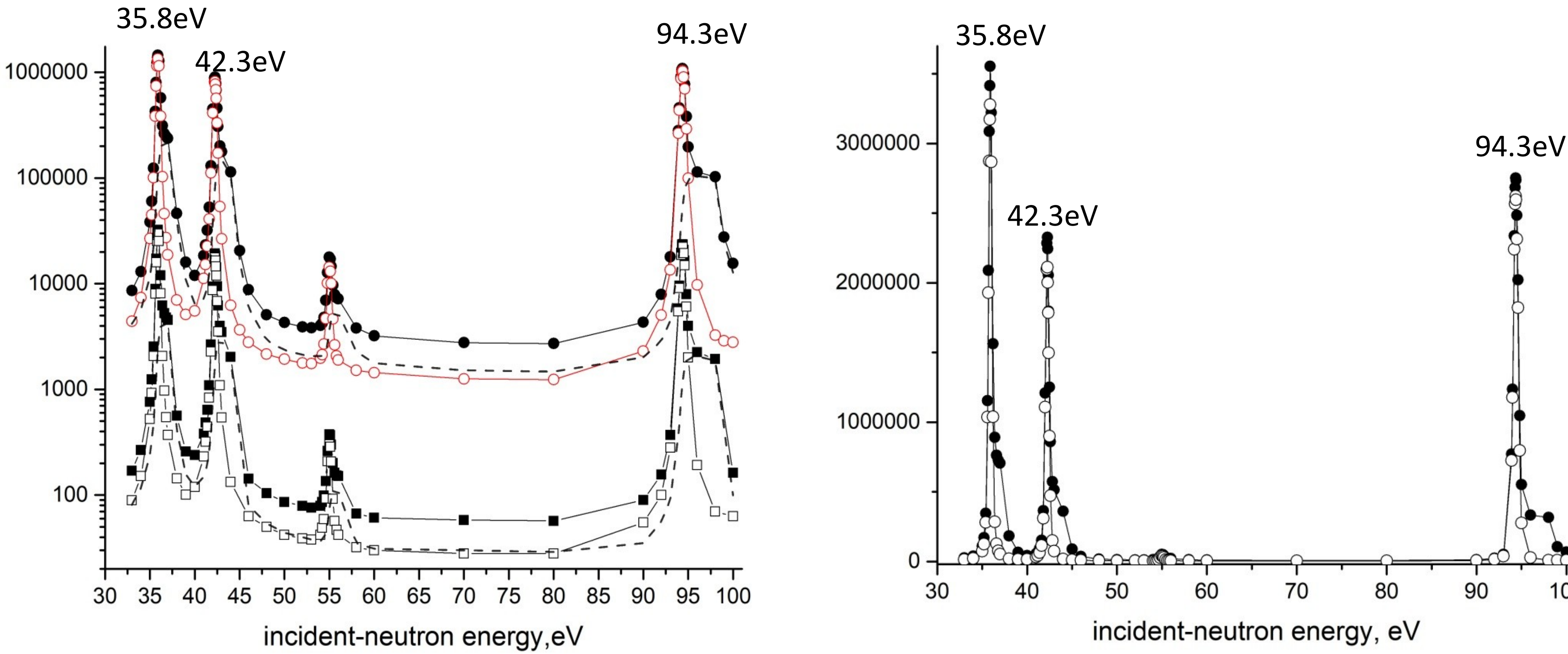
A multiple scattering of neutrons before capture always distorts the shape of neutron-capture resonances measured with the time-of-flight technique

- The target must be thick enough for a high statistical accuracy.
- The target is need to be as thin as possible for minimization of a contribution of γ-detection forward-backward asymmetry due to geometry and kinematics.
- It might be as well to choose a target with a thickness, which provides an absolute advantage of capture of neutrons without scattering in the target.

The neutron capture by ^{93}Nb targets with **cross sizes** of **4×4 cm** and **thicknesses** of **0.004, 0.2** and **0.6 cm** were calculated under the assumptions:

- 10^7 of neutrons run into the target with given initial energy;
- capture and scattering cross sections for ^{93}Nb with Doppler broadening were taken from the data-base of JAEA Nuclear Data Center JENDL-5, https://wwwndc.jaea.go.jp/jendl/j5/j5.html

Neutron capture in ^{93}Nb-targets



Numbers of captured neutrons in ^{93}Nb-targets of thicknesses Th:

from the left: Th=0.004 cm (squares of the bottom spectra) and Th=0.2 cm (circles of the upper spectra); from the right: Th=0.6 cm. Closed points and squares– total-captured neutrons, open points and squares– neutrons captured without scattering, dashed curves– contributions of multiple-scattered neutrons.

The results of neutron-capture calculations

- There is a noticeable asymmetry of the neutrons total-capture peaks (bumps from the side of incident-neutron energies bigger than peak-maxima energies due to energy losses of scattered neutrons).

- In the niobium targets with thicknesses of 400 mcm and 2 mm, neutron multiple scattering before capture is practically absent. But for the 6 mm-target contribution of neutrons captured after multiple scattering is not negligible.

- Even at the energies of maxima of investigated p-wave resonances , a majority of incident neutrons pass through the target of 2mm-thickness without capture or scattering (81% at the 35.8 eV peak-energy, 87% at 42.3 eV and 83% at 94,3 eV), and in 6 mm-target such neutrons are more than a half (53%, 65% and 58%, correspondingly).

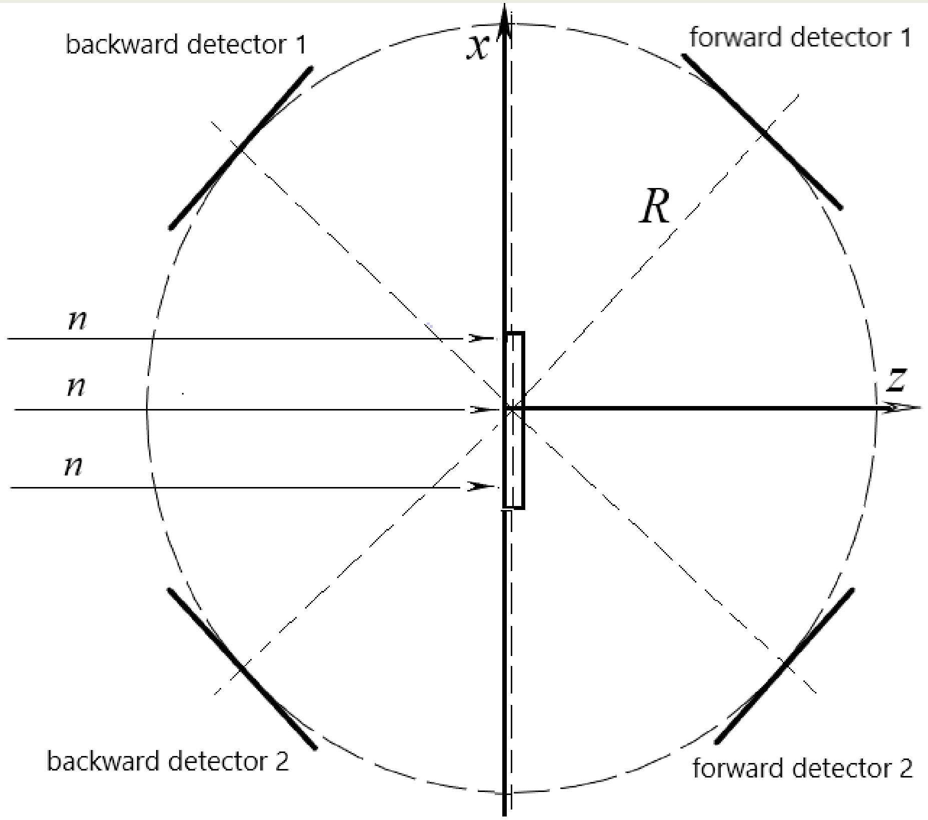
- And only (0.3–0.4)% of incident neutrons are captured or scattered in the 400 mcm-foil at the energy of resonances’ maxima.

Kinematic and geometrical forward-backward asymmetry of γ-quanta recording

The asymmetry caused by a geometry of the experiment and energy losses of scattered neutrons was calculated under an assumption of

isotropic emission of only one γ-quantum in the point of neutron capture

- γ-quanta are recorded by 4 detectors placed at R=20 cm distance from the ^{93}Nb targets (4×4 cm plates with thicknesses of 0.004, 0.2 and 0.6 cm) at 45°, 135°, 225° and 315°;
- the entry windows of the detectors: 6.5 cm in width and 7.6 cm in height.



The X-Z plane view for calculations of gammas recorded by forward and backward detectors.

Forward-backward asymmetry of recorded γ-quanta

The forward-backward asymmetry of detected gammas

$$\mathrm{eff}(E) = \frac{N_{1f}(E) + N_{2f}(E) - N_{1b}(E) - N_{2b}(E)}{N_{1f}(E) + N_{2f}(E) + N_{1b}(E) + N_{2b}(E)} = \frac{N_{forw}(E) - N_{bacw}(E)}{N_{forw}(E) + N_{bacw}(E)}.$$

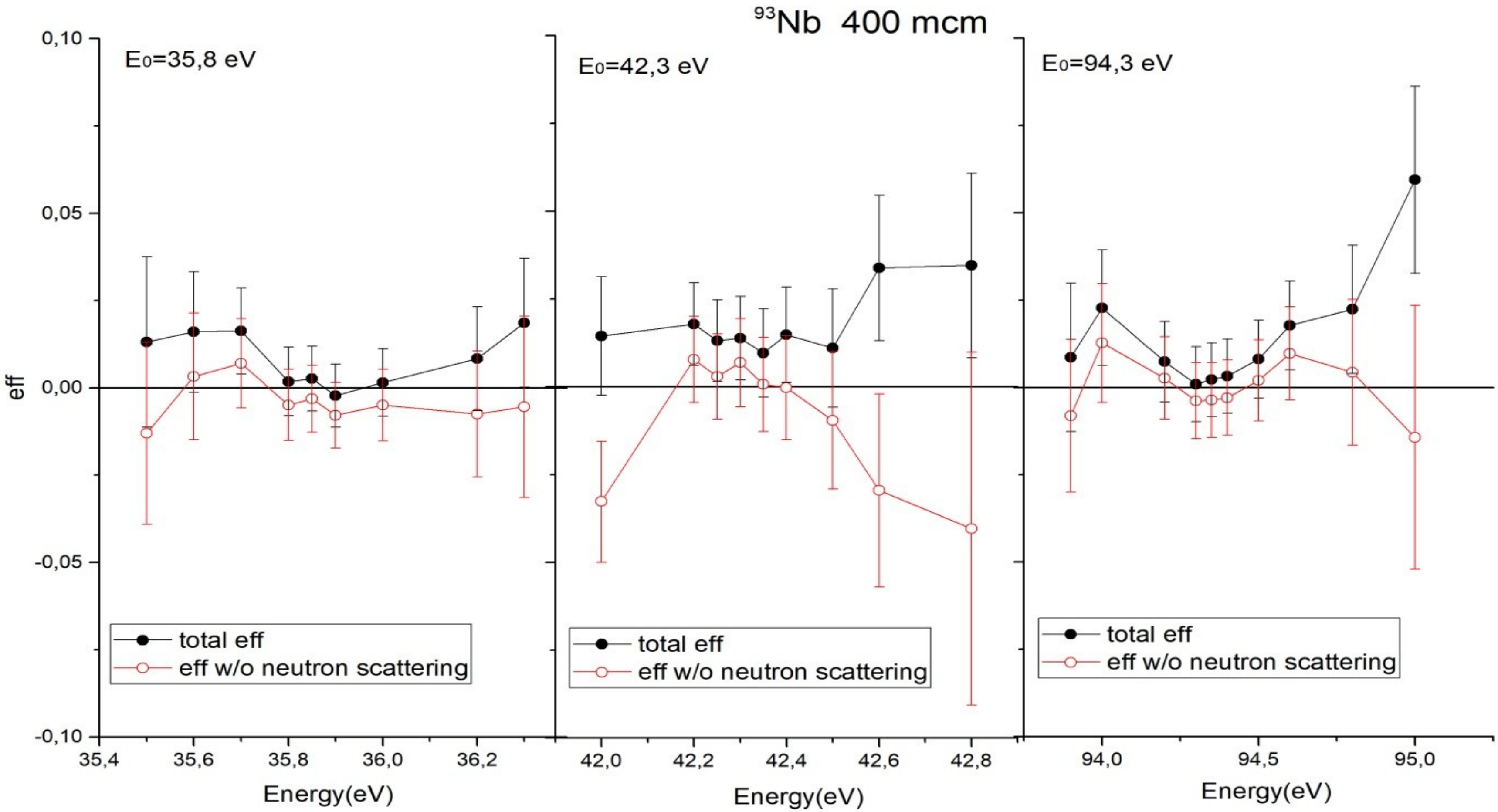
$N_{1f}(E)$ and $N_{2f}(E)$ - counts of γ-quanta recorded by forward detectors
$N_{1f}(E)$ and $N_{2b}(E)$ - counts of gammas recorded by backward detectors

An absolute uncertainty $\Delta\varepsilon(E)$ of foregoing ratio taking into account statistical errors of summary counts

$$\Delta\mathrm{eff}(E) = \mathrm{eff}(E)\sqrt{\frac{1}{N_{forw}(E) + N_{bacw}(E)} + \frac{N_{forw}(E) + N_{bacw}(E)}{\left(N_{forw}(E) - N_{bacw}(E)\right)^2}}\ .$$

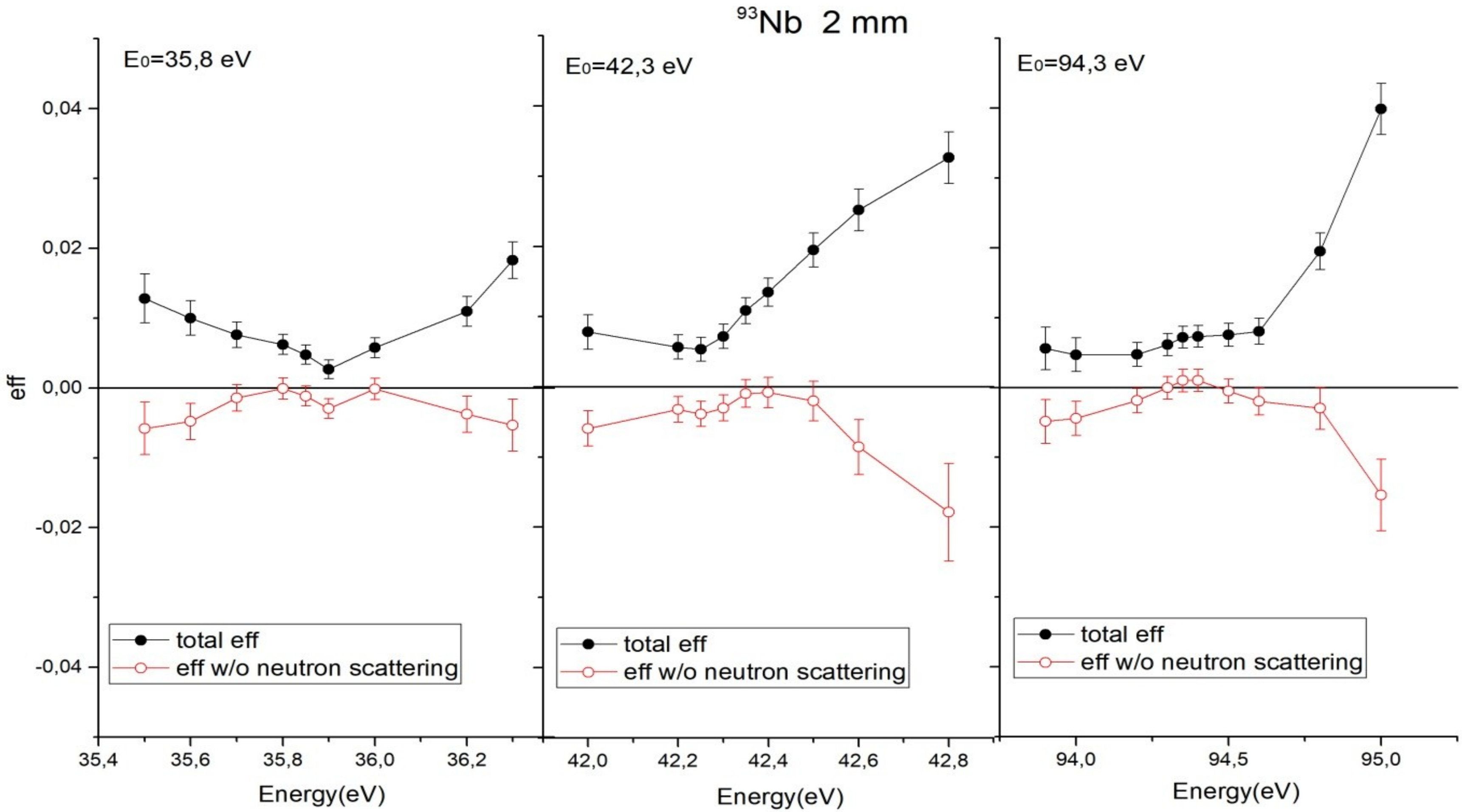
Forward-backward asymmetry of γ-detection near p-wave resonances of ^{93}Nb at the neutron energies 35.8, 42.3 and 94.3 eV

Differences in numbers of gammas recorded by forward and backward detectors were calculated for 10^8 incoming neutrons of given initial energy.



Closed points – total forward-backward asymmetry effect , open points – asymmetry effect for γ-quant recorded if neutrons are captured without scattering in the target.

Forward-backward asymmetry of γ-detection near p-wave resonances of ^{93}Nb at the neutron energies 35.8, 42.3 and 94.3 eV



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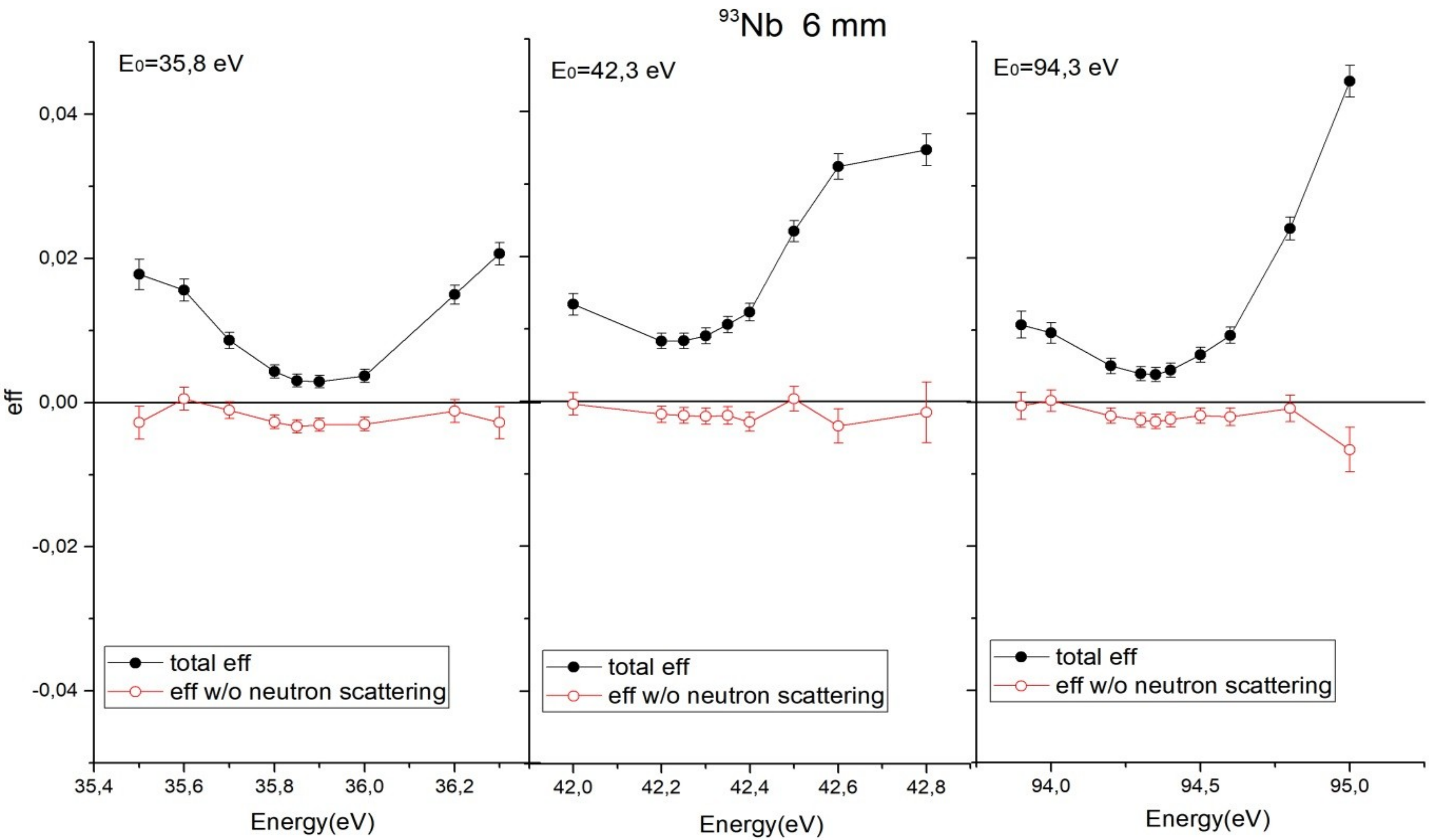

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Conclusion

1. The statistically significant result cannot be obtained with 400 mcm ^{93}Nb target .
2. There is an advantage of captured unscattered and single-scattered neutrons in the targets of considered thicknesses. Even for 6 mm-target a part of multiple-scattered neutrons in total capture is small (□3–4 %) in comparison with contribution of single-scattered neutrons.
3. All the considered ^{93}Nb-targets are not quite thick in order for a majority of incident neutrons to pass through them without capture or scattering.
4. Under condition of isotropic γ-emission from ^{93}Nb(n,γ) reaction, the contribution of forward-backward asymmetry of γ-detection at the neutron energies near considered low-energy p-wave resonances at given target thicknesses is no more than 5%.