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Low-energy neutron-neutron scattering studied with pion photoproduction on the deuteron

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The low-energy neutron-neutron scattering has been studied by analyzing the final nn interactions in $nd \to nnp$ (n,p,d are neutron, proton and deuteron, respectively) and $\pi^- d \to nn\gamma$ data. The resulting neutron-neutron scattering length (a_{nn}) differs from the proton-proton one (a_{pp}), indicating the charge symmetry breaking of the nuclear force. However, the situation is not conclusive enough because the result from $nd \to nnp$ does not agree with that from $\pi^- d \to nn\gamma$. Also, the analysis of $nd \to nnp$ could suffer from three-nucleon force effects which have not been well-established yet, while the $\pi^- d \to nn\gamma$ data have a hard-to-control uncertainty of the neutron detection efficiency. Thus an independent and different determination of a_{nn} is highly desirable. We discuss the possibility of extracting a_{nn} and effective range r_{nn} from cross section data ($d^2\sigma/dM_{nn}/d\Omega_\pi$), as a function of the nn invariant mass M_{nn}, for π^+ photoproduction on the deuteron ($\gamma d \to \pi^+ nn$). The analysis is based on a $\gamma d \to \pi^+ nn$ reaction model in which realistic elementary amplitudes for $\gamma p \to \pi^+ n$, $NN \to NN$, and $\pi N \to \pi N$ are built in. We show that M_{nn} dependence (lineshape) of a ratio $R_{\rm th}$, $d^2\sigma/dM_{nn}/d\Omega_\pi$ normalized by $d\sigma/d\Omega_\pi$ for $\gamma p \to \pi^+ n$ and the nucleon momentum distribution inside the deuteron, at the kinematics with $\theta_\pi = 0^\circ$ and $E_\gamma \sim 250$ MeV is particularly useful for extracting a_{nn} and r_{nn} from the corresponding data $R_{\rm exp}$. It is found that $R_{\rm exp}$ with 2% error, resolved into the M_{nn} bin width of 0.04 MeV (corresponding to the p_π bin width of 0.05 MeV/c), can determine a_{nn} and r_{nn} with uncertainties of ± 0.21 fm and ± 0.06 fm, respectively, for the case of $a_{nn} = -18.9$ fm and $r_{nn} = 2.75$ fm. The requirement of such narrow bin widths indicates that the momenta of the incident photon and the emitted π^+ have to be measured with high resolutions. This can be achieved by utilizing virtual photons of very small Q^2 from electron scattering at Mainz MAMI facility. The proposed method for determining a_{nn} and r_{nn} from $\gamma d \to \pi^+ nn$ has a great experimental advantage over the previous one utilizing $\pi^- d \to \gamma nn$ for being free from the formidable task of controlling the neutron detection efficiency and its uncertainty. This presentation is based on our recent work [1]. [1] S.X. Nakamura, T. Ishikawa, and T. Sato, arXiv:2003.02497.

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