Is the Property of Mesons Modified in the Nuclear Medium?
– ϕ Meson Photoproduction from Nuclei –

The concept of mass modification is generally applied for many fields in physics. The effective mass of electrons in material science is widely discussed, for example, when calculating the conductivity. In nuclear physics, the concept of the effective mass is sometimes used to describe the effect of the average potential. In these cases, we believe that the bare mass does not change and the concept of "effective mass" is treated as a conventional method of taking into account the potential effect from the medium. A similar concept is applicable to treating mesons in hadron physics.

The modification of vector mesons in nuclear matter is an interesting subject since its origin stems from the chiral symmetry violation or recovery in a nuclear medium. Theoretically, a broadening of the width and/or a decrease of the mass has been predicted for the ϕ meson with a pure $s\bar{s}$ component in the nuclear medium [1,2], although no clear evidence for the mass shift of the ϕ meson has been reported.

The total ϕ-nucleon cross section $\sigma_{\phi N}$ in free space determined from the ϕ photoproduction on the proton is very small, 7.7-8.7 mb [3]. If $\sigma_{\phi N}$ in the nuclear medium is the same as that in free space, the ϕ photoproduction cross section from nucleons in a nucleus (incoherent process) σ_A should be approximately proportional to the mass number of the target nuclei A since the ϕ meson produced in the nucleus almost goes out the nucleus because the mean free path is much longer than the nuclear size. If $\sigma_{\phi N}$ becomes larger in the nuclear medium, some fraction of photoproduced ϕ mesons would interact with nucleons in the nucleus and disappear via inelastic reactions such as $\phi p \rightarrow K^+\Lambda$ and $\phi n \rightarrow K^-\Sigma^+$. In this case, the A-dependence considerably deviates from $\sigma_A \propto A^1$, as illustrated in Fig. 1. Therefore, we can study the properties of the ϕ meson in the nuclear medium by measuring the ϕ photoproduction cross sections from nuclei.

The ϕ photoproduction cross sections from Li, C, Al, and Cu nuclei were measured at beamline **BL33LEP**. High energy photons were obtained by backward Compton scattering in the 8 GeV storage ring. The produced ϕ mesons with a decay mode to K^+ and K^- meson pairs were detected at forward angles using a magnetic spectrometer. Figure 2 shows the invariant mass spectrum reconstructed by the momentum information of K^+ and K^- mesons for the $\gamma Cu \rightarrow K^+K^-X$ reaction. A peak corresponding to ϕ mesons was clearly observed, and similar peaks were also observed in the runs with other targets. The measured mass and width of the ϕ meson for each target nucleus are consistent with the free ϕ meson mass of 1.02 GeV.

Among the ϕ meson events produced, we identified ϕ mesons produced not from individual nucleons in a nucleus (incoherent process) but from the nucleus as a whole (coherent process). The A-dependence of the ϕ photoproduction cross section of the incoherent process gives the relation $\sigma_A \propto A^{0.72\pm0.07}$ shown in Fig. 3 after subtracting the contribution of coherently produced ϕ mesons as background.

To determine $\sigma_{\phi N}$ from the obtained A-dependence, an optical model of a Glauber-type multiple scattering theory for incoherent production is applied [4]. The value of $\sigma_{\phi N}$ is estimated to be 35^{+17}_{-11} mb, which is much larger than $\sigma_{\phi N}$ in free space. This suggests that the properties of ϕ mesons might change in the nuclear medium.

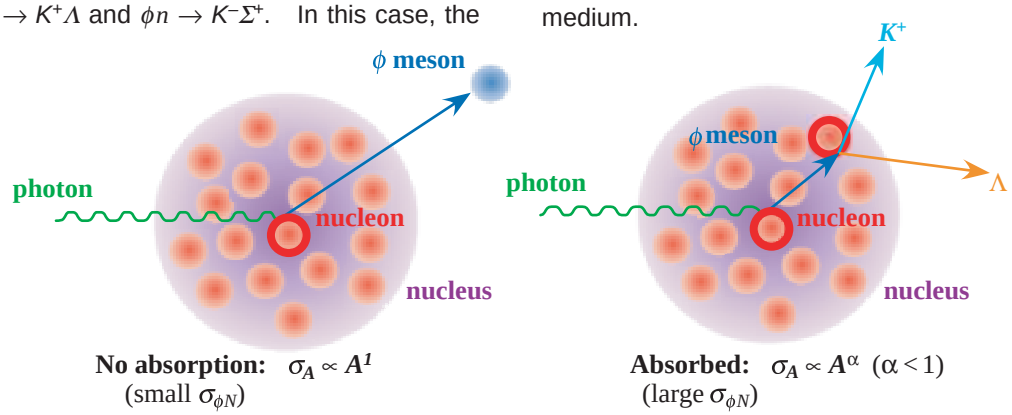

Fig. 1. Left: when ϕ mesons are produced in a nucleus and go out, the A-dependence is proportional to A. Right: If there is a considerable deviation of the ϕ-N interaction cross section in the nuclear medium, the cross section becomes large.

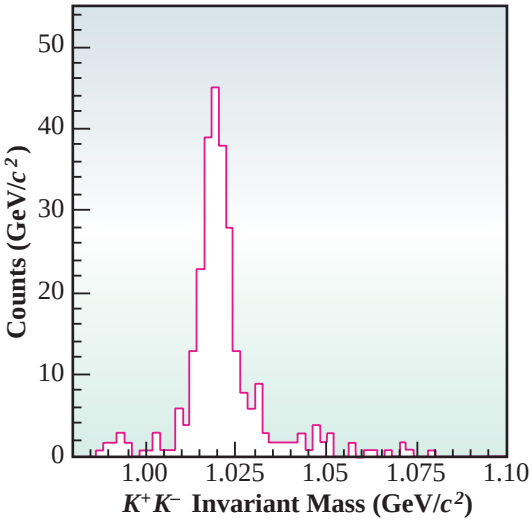

Fig. 2. K^+K^- invariant mass spectrum for $\gamma Cu \rightarrow K^+K^-X$ reaction.

On the basis of the self-energy calculation for ϕ mesons in the nuclear medium, Cabrera *et al*. presented the *A*-dependence in terms of the variable $P_{out} = \sigma_A / A\sigma_N$ which represents the probability of a photoproduced ϕ meson going out a nucleus [5], where σ_N denotes the ϕ photoproduction cross section from a nucleon. Figure 4 compares the P_{out} obtained in the experiment and the theoretical predictions given by Cabrera *et al*. as a function of *A*. The obtained P_{out} are smaller than the theoretical predictions. This discrepancy implies that the ϕ-nucleon interaction is stronger than that estimated theoretically due to the modification of the ϕ properties in the nuclear medium.

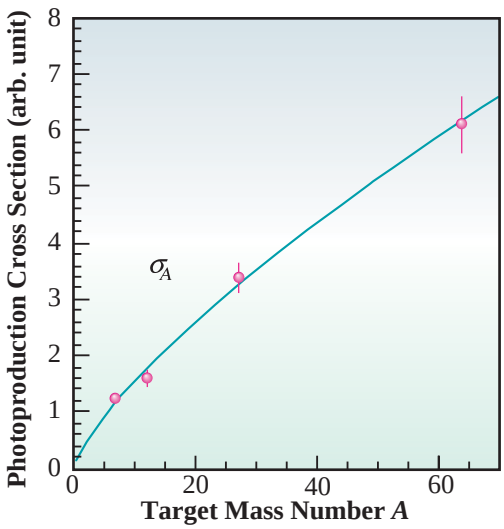

Fig. 3. *A*-dependence of ϕ photoproduction cross section of the incoherent process. The data points are fitted as a function of $A^{0.72}$.

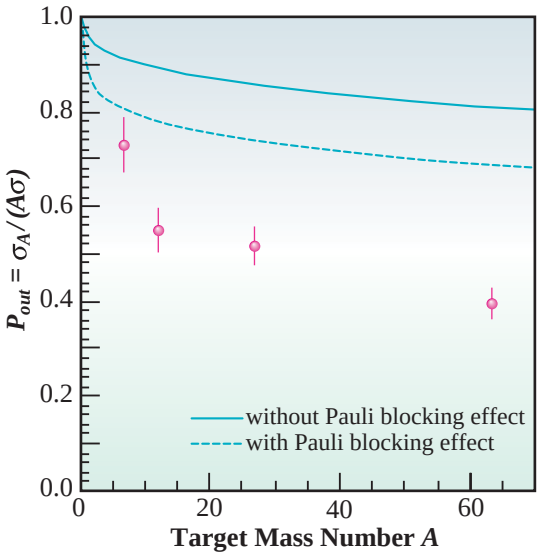

Fig. 4. Probability P_{out}. The solid and dashed curves show the theoretical calculations given by Cabrera *et al*. [5] without and with the Pauli-blocking effect, respectively.

Takatsugu Ishikawa [a,*] and Mamoru Fujiwara [b,c]

(a) Laboratory of Nuclear Science, Tohoku University
(b) Research Center for Nuclear Physics, Osaka University
(c) Advanced Photon Research Center, Japan Atomic Energy Research Institute

*E-mail: ishikawa@lns.tohoku.ac.jp

References

[1] T. Hatsuda, S.H. Lee: Phys. Rev. C **46** (1992) 34.
[2] E. Oset *et al.*: Phys. Lett. B **508** (2001) 237.
[3] H.-J. Behrend *et al.*: Phys. Lett. B **56** (1975) 408.
[4] K.S. Kölbig and B. Margolis: Nucl. Phys. B **6** (1968) 85.
[5] D. Cabrera *et al.*: Nucl. Phys. A **733** (2004) 130.
[6] *T. Ishikawa, D.S. Ahn, J.K. Ahn, H. Akimune, W.C. Chang, S. Daté, H. Fujimura, M. Fujiwara, K. Hicks, T. Hotta, K. Imai, H. Kawai, K. Kino, H. Kohri, T. Matsumura, T. Mibe, K. Miwa, M. Miyabe, M. Morita, T. Murakami, N. Muramatsu, H. Nakamura, M. Nakamura, T. Nakano, M. Niiyama, M. Nomachi, Y. Ohashi, T. Ooba, D.S. Oshuev, C. Rangacharyulu, A. Sakaguchi, Y. Shiino, Y. Sakemi, H. Shimizu, Y. Sugaya, M. Sumihama, Y. Toi, H. Toyokawa, C.W. Wang, T. Yorita, M. Yosoi and R.G.T. Zegers: Phys. Lett. B **608** (2005) 215.*