Experimentral study of the chiral symmetry in nuclear matter — from KEK-PS E325 to J-PARC E16 —

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Dynamical breaking of the chiral symmetry as a mass generation mechanism of hadrons, which was proposed by Nambu, is widely accepted now. However, there is no experimental evidence so far. Measurements of the mass modification of hadrons in a finite temperature and/or density environment, where the broken chiral symmetry is thought to be restored, have been proposed and performed.

We performed an experiment KEK-PS E325 from 1997 to 2002, in order to measure the vector-meson mass modifications in nuclei, as a finite density environment. We constructed a large acceptance spectrometer[1] to measure the e^+e^- and K^+K^- pairs from decays of low-mass vector mesons, namely ρ, ω and ϕ. They were generated in target nuclei using the 12-GeV proton-induced reactions. The beam intensity was typically 1×10^9 protons/spill and mainly C and Cu targets were used.

In the $\phi \to e^+e^-$ invariant mass spectra, we observed an significant excess, on the low-mass side of the ϕ meson peak, over the expected spectrum taking account of the experimental distortions like the multiple scattering and the radiative effects[2]. The excess was only observed in the slowest division of the Cu-target data, which are divided by the $\beta\gamma(= p/m)$ of reconstructed mesons. This is consistent with a naive 'matter-size effect' on the mass spectra. This means that the number of modified meson is expected to be larger for the slower mesons and for the larger-size target nuclei, because such mesons have larger probability of inside-nuclear decay. Note that almost all the ϕ mesons in the observed momentum are expected to decay outside nucleus. The 3.4 % of mass-reduction which is deduced from the data are consistent with a theoretical prediction based on the QCD sum rule[3]. In the $\rho/\omega \to e^+e^-$ spectra, significant excesses which cannot be explained by the known hadronic sources were observed on the low-mass side of ω-meson peak in the data of both targets[4]. In the e^+e^- decay channel, we cannot distinguish ρ and ω. Under the assumption that the mass reduction of ρ and ω is same, the deduced mass-reduction is almost consistent with the prediction in [3].

A possible change of the branching ratio $\mathrm{Br}(\phi \to K^+K^-)$ is another signature of the in-medium mass modification of ϕ (and/or K). Generally speaking, the $\phi \to K^+K^-$ decay is suppressed in nuclei in the case that m_ϕ is reduced and $(m_{K^+} + m_{K^-})$ is not changed, because the phase space of the $\phi \to K^+K^-$ decay is reduced, and vice versa. A mass-number dependence of the ratio $\mathrm{Br}(\phi \to K^+K^-)/\mathrm{Br}(\phi \to e^+e^-)$ was examined and a tendency of the K^+K^--enhancement is observed with a significance of 1.2 σ[5].

At the J-PARC hadron experimental facility, we proposed the experiment E16[6], which perform a systematic study of the mass modification of vector mesons decaying in nuclei through the e^+e^- invariant mass spectra.

To make vector mesons in target nuclei, we would use a high intensity proton beam, about 10^{10} protons/spill. The beam energy is required to be 10 GeV or more. Since secondary beams are unavailable to achieve such high intensity in these energies, we need to use the primary proton beam. Both of the 30 and 50 GeV primary beams are acceptable.

In five weeks of physics run with the beam described above, we can accumulate the $1 \sim 2 \times 10^5$ of ϕ mesons in the e^+e^- decay channel for each nuclear target, namely, CH_2, C, Cu and Pb. In addition, approximately 10^6 of ρ and ω mesons and approximately 10^3 of J/ψ can be collected simultaneously. With the statistics, which are 100 times as large as that accumulated in E325, we can observe the excess in the ϕ-meson spectra in the data of other targets than Cu. Then we can compare the tendency of $\beta\gamma$ dependence of the spectrum in each target with theoretical predictions, and we can decouple the intrinsic momentum dependence of the mass spectrum, which is predicted as in [7], from the matter-size effect. The systematic and decisive data are awaited to lead a progress of theoretical studies.

The proposal of the experiment has obtained the physics approval by PAC. Toward the full approval, the detector development is on going at U-Tokyo and RIKEN with some small grants including a Grant-in-Aid acquired in 2007 for this experiment.

At J-PARC, other experiments are proposed to investigate the chiral symmetry in nuclear matter. They plan to use the different approach, namely, the measurements of the production of (η, ω, ϕ)-mesic nuclei and the meson decay from the bound state. They use the $1 \sim 2$ GeV/c π (or $\bar{p}$)-induced reaction in secondary beam lines.

References

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