【Grant-in-Aid for Scientific Research (S)】

A study of the ϕ meson mass generation mechanism in K-meson pair decays inside nuclei with polarizations and dispersion relations

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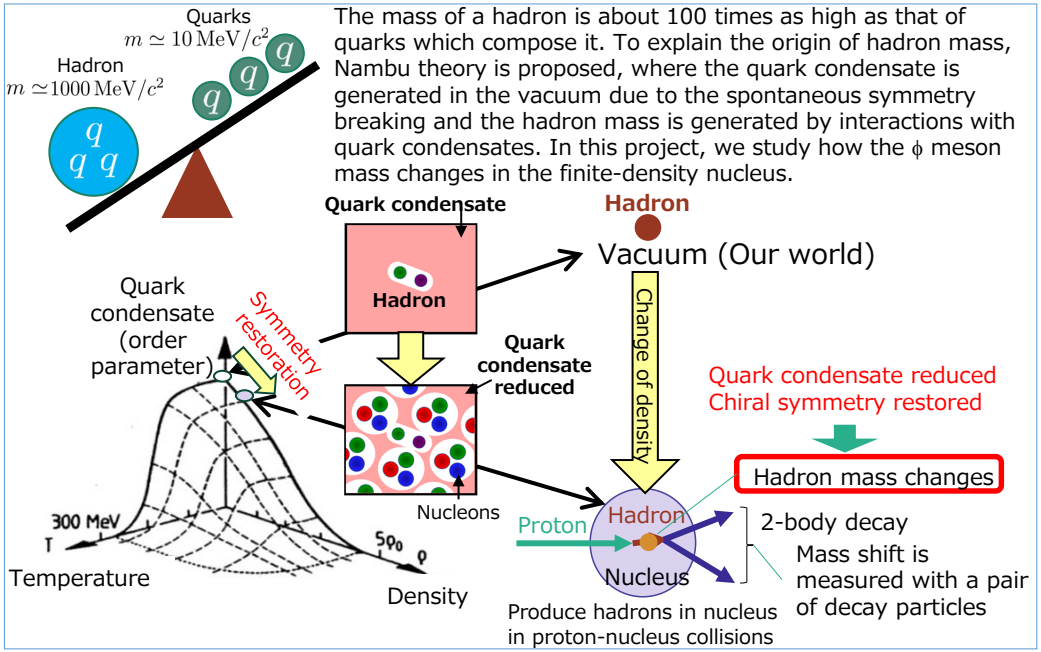
Project Information	Project Number : 25H00400　　Project Period (FY) : 2025-2029 Keywords : ϕ meson, chiral symmetry, quark condensate, J-PARC

Purpose and Background of the Research

●Outline of the Research

How is the mass of visible materials such as our bodies, materials in the earth, and stars in the universe generated? Most of it is explained by the spontaneous symmetry breaking in Nambu Theory. In this research project, we irradiate a high-intensity proton beam on the nuclear targets, produce ϕ mesons inside the nuclei, and measure the K-meson pairs to evaluate the ϕ mass shift with high precision. We aim to unravel the hadron mass generation mechanism experimentally.



The mass of a hadron is about 100 times as high as that of quarks which compose it. To explain the origin of hadron mass, Nambu theory is proposed, where the quark condensate is generated in the vacuum due to the spontaneous symmetry breaking and the hadron mass is generated by interactions with quark condensates. In this project, we study how the ϕ meson mass changes in the finite-density nucleus.

Figure 1. The schematic view of this research project

●Experimental method

We irradiate a high-intensity proton beam to nuclear targets and measure ϕ decayed inside nuclei.

A measured mass distribution (red points) is a superposition between a distribution by ϕ decayed outside the nucleus without a mass shift (black line) and ϕ decayed inside the nucleus with a mass shift (cyan area). From the latter we evaluate the mass shift.

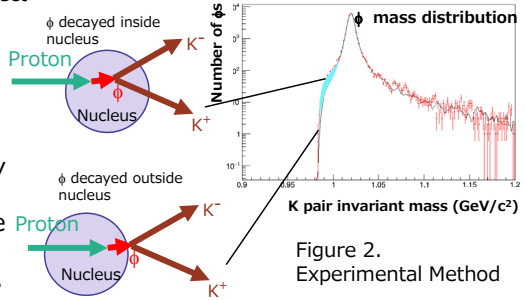


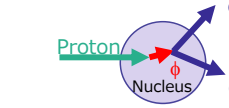
Figure 2. Experimental Method

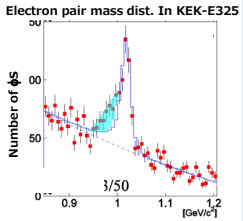
● Features of this project

With the narrow ϕ meson mass peak, we will measure the ϕ mass shift precisely. Using K meson-pair decays with higher-decay probability instead of electron-pair decays in previous experiments, we will collect several hundreds of times as high statistics data as the KEK experiment.

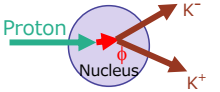
- By measuring ϕ mass at rest in the nuclei with a few % errors, we evaluate the quark condensate quantitively.
- We will measure for the first time different momentum-dependences of mass in longitudinal and transverse polarization, predicted in a theory.

Previous/current exp. : ϕ→e⁺e⁻
KEK-E325: **2400 events**
J-PARC E16 **: 30K events**





This project
New exp. : ϕ→K⁺K⁻
High stat.: 1 M events



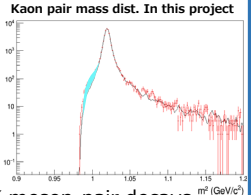


Figure 3. Electron-pair and K meson-pair decays.

Expected Research Achievements

●Study of the mass generation mechanism with the momentum and polarization dependent mass shifts

As Fig. 4, we introduce three kinds of K meson identification detectors in the existing spectrometer (J-PARC E16), with which we successfully identified K mesons (Fig. 5) in 2024. Using them, we will measure ~1M events of K meson pair decays of ϕ in p+C, p+Cu and p+Pb reactions. We will measure momentum dependence of ϕ mass shifts with the statistical errors shown in Fig. 6. From this, we aim to evaluate quantitatively quark condensate and high-order quark and gluon condensates and unveil the relation between the vacuum structure at the nuclear density, and hadron mass.

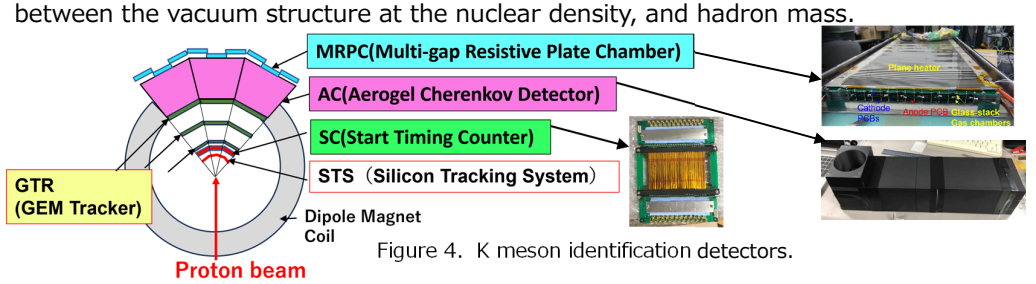


Figure 4. K meson identification detectors.

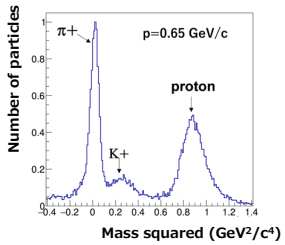
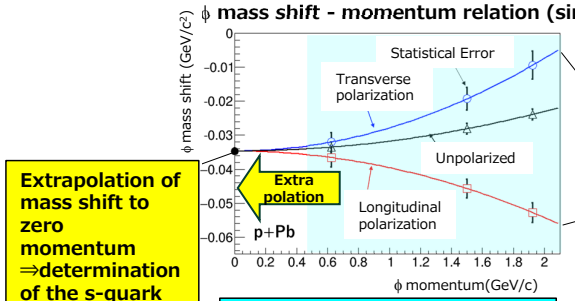


Figure 5. The mass-squared distribution measured in the beam test at J-PARC in 2024, where K⁺ is identified.



Extrapolation of mass shift to zero momentum ⇒determination of the s-quark condensate

Clarify the relation of the hadron mass and the vacuum structure at finite density

World's first measurement: Polarization and momentum dependent mass shift ⇒Evaluation of high-order quark and gluon condensates

Figure 6. The momentum dependence of ϕ mass expected in this project.

Homepage Address, etc.	A home page of this project will be open in early JPY2025. The home page of Research Group of Hadron and Nuclear Physics at JAEA; https://asrc.jaea.go.jp/soshiki/gr/hadron/