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

Precise measurement of di-electron decay of mesons and the chiral condensate in nuclei

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Project Information	Project Number : 23H05440 Project Period (FY) : 2023-2027 Keywords: experimental nuclear physics, QCD, GEM, Tracking detector, electron identification detector

Purpose and Background of the Research

●Outline of the Research

Mass of elementary particles are generated by the Higgs mechanism, 10 picosecond after the Big Bang. However, 0.1 millisecond after, the universe became more cool, quarks obtained further heavier mass due to the chiral condensate and compose hadrons as nucleons. Significant fraction of mass of visible materials was generated at this time (Fig.1 upper). Chiral condensate is thought to be zero at the high temperature and also the high density. At the normal nuclear density, it is not zero but significantly reduced (Fig. 1, lower-right). Thus, in the nuclei, mass of hadrons is thought to be changed. Such phenomena have been predicted based on the QCD. We have already published on the signature of the change of vector meson mass spectra in nuclei in 2006-7, as results of the KEK-PS E325 experiment. In spite of many experiments in the world reported the spectral change of mesons, only we observed the change of the phi meson spectra. In order to confirm this study, we have proposed J-PARC E16. We will perform systematic measurements with the 10 times as much statistics as that of E325. We will establish the spectral change of mesons in nuclei, compare them with theoretical calculations, and show the evidence of the mass generation mechanism of hadrons.

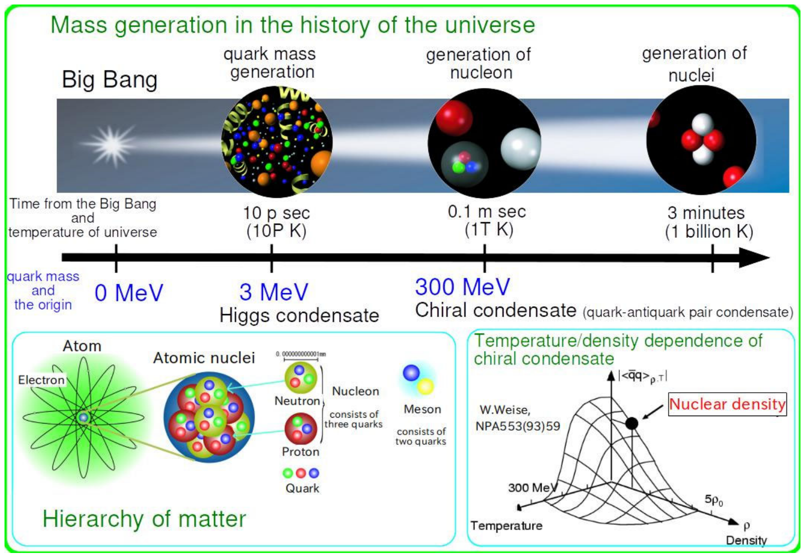

Figure 1. Mass generation mechanism and the history of the Universe

●Research methods

We construct a new spectrometer at High-momentum beamline which was completed in 2020 at J-PARC Hadron experimental facility and measure the electron-positron pairs from the vector-meson decays. We radiate the 30-GeV primary proton beam from the J-PARC MR to very thin targets (C/Cu/Pb) to generate vector mesons in nuclei.

●(Research methods: cont'd)

Electrons and positrons are measured by GEM Tracker (GTR), which achieves the 0.1 mm of position resolution in tests, thus the evaluated mass resolution is 6-8 MeV for phi mesons, better than that of E325. To identify the electrons, the combination of Hadron Blind Gas Cherenkov Detector (HBD) and Lead-glass calorimeter (LG) is used. The spectrometer for the first physics data taking was almost completed, by previous Grant-in-Aids (Fig.2). Test operation of beamline and spectrometer was already started.

Two physics data-taking runs are planned in this research, each takes about 60 days. Addition of detector modules is planned for the second run.

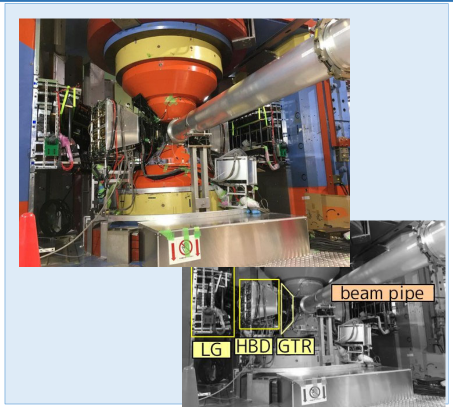

Figure 2. Spectrometer

Expected Research Achievements

●As a model-independent analysis, we compare the measured invariant mass distribution of mesons with the vacuum-expected shape (Fig. 3) and difference between the two will be examined systematically. The amount of difference could be depend on the meson velocity and nuclear size, namely, the number of modified meson could be much for more slowly-moving mesons and for larger nuclei, where the probability of inside-nuclear decay is expected higher (Fig. 4). Statistically-significant such dependence are the evidence of the spectral change of mesons in nuclei.

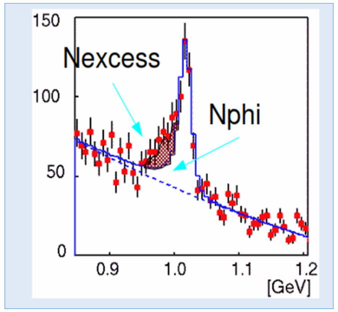

Figure 3. Amount of difference (Nexcees) between the data (red) and the vacuum shape (blue line).

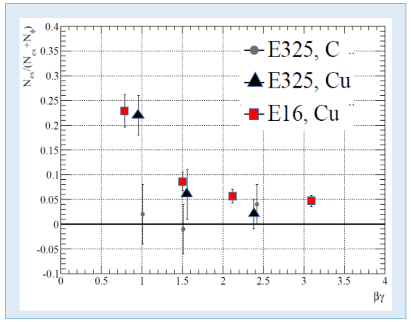

Figure 4. Significant difference and velocity dependence will be observed in this research, first physics run (red: simulation result). Black show the E325 results: only Cu slow is significant.

●Also, we compare the data with theoretical calculations of spectral change. Once we reproduce the data shape by fitting with a model calculation, mass change of mesons at the normal nuclear density could be deduced. Further, a momentum dependence of such mass (dispersion relation of mesons in nuclear matter: Fig. 5) is compared with theoretical calculations and deduce the chiral condensate in nuclei.

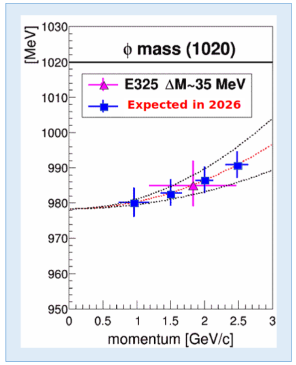

Figure 5. Dispersion relation of phi meson expected by this research (blue) and a point of E325 result (pink, PRL 98(08)042501). Lines are theoretical curve (S.H.Lee, PRC57(98)927 & NPA 670(00)119).

Homepage Address, etc.	https://ribf.riken.jp/~yokkaich/E16/E16-index.html