資 料 3

Letter of Intent

Combined measurements of nuclear ω bound state and ω mass modification in p(π^-, n)ω reaction

November 30, 2007

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1 Introduction

The origin of the mass of hadrons has been drawing strong interest in nuclear and particle physicists. In QCD, mass of hadrons is composed of a sum of the effective mass of valence quarks, known as constituent quark mass, and their interaction term. The effective mass of valence quarks is determined by chiral property of QCD vacuum. This mechanism is understood as a consequence of the dynamical breaking of chiral symmetry. In hot and/or dense matter, this broken symmetry will be restored either partially or completely and, hence, properties of hadrons, such as mass, decay modes and life time, can be modified. Therefore we can study the chiral property of QCD vacuum by measurements of the in-medium decay of vector mesons. In this proposed experiment, we focus on vector meson mass in nucleus, since relatively large mass modification is theoretically expected even at nuclear density [1]. Nucleus can be considered as a "static" nuclear matter. While, with hot nuclear matter, such as high energy heavy ion collisions, the density and temperature of generated matter are not stable during a collision and it makes hard to extract chiral properties of the matter from measurements.

Two experimental approaches have been to study hadron properties in nucleus. One is focused on meson bound states in nucleus and another is a direct measurement of mass and decay width via meson decay. At the moment, two kinds of approaches are realized in independent experiments and no experiment has performed simultaneous measurements.

One remarkable result is achieved by GSI-S236 group [2]. They observe deeply bound 1s states of π^- in ^{115,119,123}Sn using the Sn(d,^{3}He) pion-transfer reaction. It's result indicates a reduction of the chiral order parameter, $f_\pi^*(\rho)^2/f_\pi^2 \approx 0.64$, at the normal nuclear density, $\rho = \rho_0$. Important results are also obtained in direct measurements of mass distribution in nucleus. The KEK-PS E325 experiment [3] measured the e^+e^- decays of light vector mesons ($\rho/\omega/\phi$) made by the 12–GeV proton induced reaction in the target nucleus. Their results suggests 9% decreasing of ρ meson mass. According to their analysis, their result is consistent with the same decreasing of ω as ρ. However, ω peak is sitting on ρ 's broad peak and the measurement has very small sensitivities for ω meson mass modification. Modification of ρ meson is also detected by TAGX-INS (KEK-TANASHI) group in $\pi^+\pi^-$ channel in γ + ^{3}He/^{12}C reaction [4]. The mass spectral modification of ω meson was measured by the CBELSA/TAPS experiment in $\pi^0\gamma$ decay channel in γA reactions [5]. Since ρ mesons have a very small branching ratio (6.0×10^{-4}) to $\pi^0\gamma$ decays, contribution of ρ meson is negligible in this measurement. Their results show 14% decreasing of ω mass. Recently, CLAS at J-Lab reported mass broadening of ρ meson, however they did not observe mass decreasing

[6]. This contradiction will be solved in another proposed experiment (E16) at J-PARC.

It can be said that the existence of the hadron modification in medium has been established in these experiments. However, the origin of the modification is not clarified yet. There are also many explanations unrelated to the chiral symmetry restoration.

Here we propose combined measurements of nuclear ω bound state and direct ω mass modification. Nuclear ω bound states are measured in p(π^-, n)ω reaction and decays of generated ω meson are also measured with $\omega \rightarrow \pi^0\gamma$ mode. Such exclusive measurement can supply essential information to establish partial restoration of the chiral symmetry in nucleus. Figure 1 shows a schematic view of combined measurements.

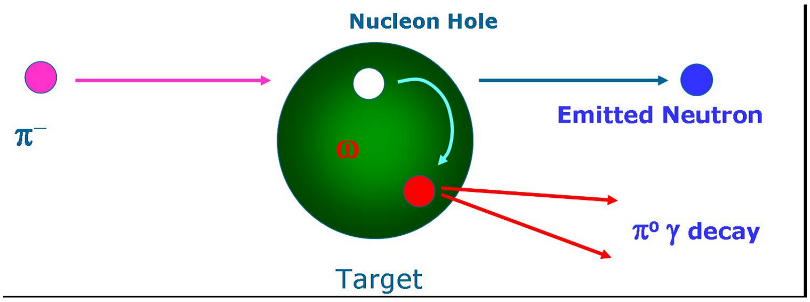

Figure 1: Schematic view of combined measurements

2 ω meson in nucleus and proposed experiment

Mass of ω meson at finite density, such as nucleus, has been studied in many theoretical methods. Hatsuda and Lee studied using a QCD sum rule and partial chiral symmetry restoration. They predicted 10$\sim$20% decreasing for ρ/ω mass at normal nuclear density [7]. Klingl *et al.* calculated the downward mass-shift and even mass broadening of $\rho/\omega/\phi$ in dense matter[8]. Some models considered couplings to baryon resonances and predicted broadening and slight increasing of ω mass[9, 10].

Calculations about possible ω bound states have been developped by several groups. W. Weise and his group predict 30 MeV binding energy [11]. H. Nagahiro *et al.* predict 50 MeV binding energy using an optical potential method [12, 13]. Figure 2 shows a prediction of ω bound sate from [13].

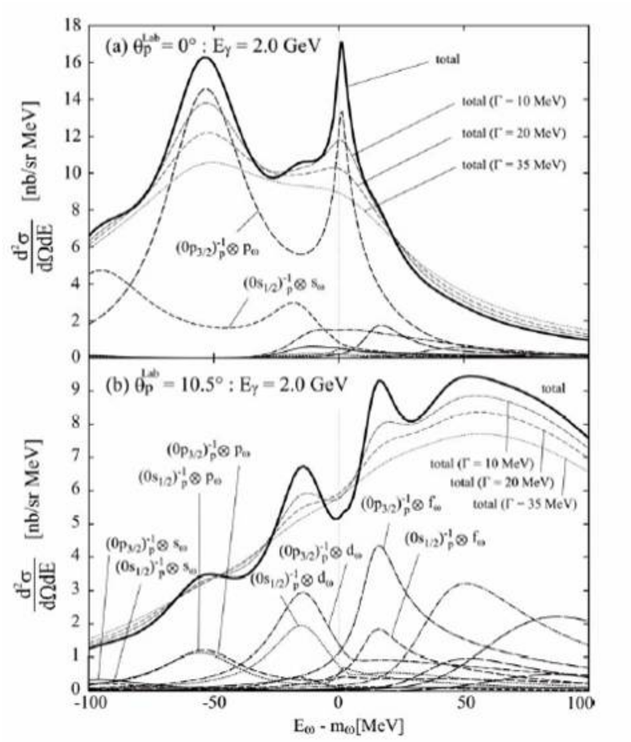

Figure 2: Possible ω bound state [13]

In addition, ω meson properties have been calculated within varied models ranging from quark models, to phenomenological evaluations, or using effective Lagrangians [14].

One of the current main questions is how we can distinguish these effects experimentally. For such purpose, an exclusive measurement is needed. When a binding energy of a ω bound state in nucleus is measured, it can be interpreted to optical potential and gives a phenomenological information about interactions between mesons and nuclei. If mass distribution of bounded ω meson is measured directly via decays, the relation between mass distribution and nuclear-meson interaction is established experimentally. Then, the amount of ω mass shift in direct mass spectrum and ω binding energy can be compared and such comparison gives information about effects beyond the meson nuclei interaction, such as chiral symmetry restoration. In terms of the QCD sum rule calculation, the calculation contains all interaction between the meson and the matter, in principle. Thus, Hatsuda's prediction may contain so called other nuclear effects. This statement can be checked in the proposed experiment.

At this moment, only TAPS measured ω meson mass spectra with high resolution. Their results are very encouraging, however the measurement is inclusive and contains all effects discussed above.

In the proposed experiment, combined measurements of nuclear ω bound state and direct ω mass modification. Nuclear ω bound states are measured in p(π^-, n)ω reaction and decays of generated ω meson are also measured with $\omega \rightarrow \pi^0\gamma$ mode. This is the first measurement to see ω bound state in nucleus.

In addition, the experiment has the first result to be compared theoretical prediction directly in measurements of mass distribution. Theoretical calculations of meson mass distribution assume that mesons exist at rest in nuclear matter. Thus, previous experiments, such as TAPS and KEK-E325, need some interpretation between experimental results and theoretical predictions to take into account kinematics of generated mesons. In the proposed experiment, measurements of nuclear ω bound states gives kinematical conditions of generated meson.

Another issue is a large background in measurements. Evaluation of combinatorial background is a major issue in the direct mass measurements via decays. M. Kaskulov *et al.* claims that TPAS results are not robust under shape difference of combinatorial background [13]. Also, huge backgrounds make observation of a broad bound state peak difficult. In the proposed experiment, each measurement helps reducing the background in another measurement and combined measurements can handle background evaluations well.

3 Experimental Apparatus

We measured p(π^-, n)ω reaction and decays of generated ω meson with $\omega \rightarrow \pi^0\gamma$ mode and pi^0 meson is detected with two γ decays. In the measurements, two detectors are needed. One is neutron detector at the forward region and another is γ detectors for detecting 3 γ's at target region.

Figure 3 shows ω momentum as a fucntion of π^- in p(π^-, n)ω reaction. According to H. Nagahiro's calculation (Fig. 2) 50MeV binding energy is expected. Thus, the beam momentum of 2.0 GeV is required. K1.8 beam line or high momentum beam line have to be used. The required beam intensity is 10^7 of π^- per spill. Also, emitted neutron should be detected

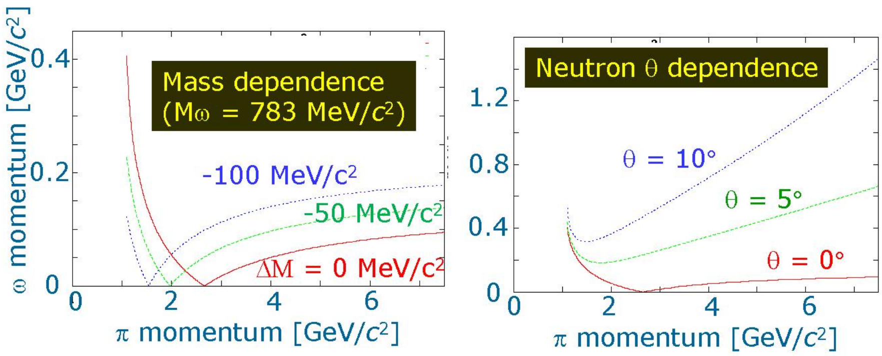

Figure 3: ω momentum as a function of π^- in p(π^-, n)ω reaction. Left: ω mass dependences. Right: emitted neutron angle dependence

at 0 degree to minimize momentum transfer of $\omega meson$. Charged particles including π^- beam is swept by a magnet, such as SKS.

Figure 4 shows a schematic view of neutron counter which measure time of flight to identify neutrons and measure neutron momentum. To achieve enough mass resolution, time resolution should be less than 80 ps. With the resolution of 80 ps and 20m flight path, 9 MeV/c^2 can be achieved. At K1.8 beam line, The maximum flight path is 7m and the mass resolution of 30 MeV/c^2 is achieved. The counter has 4 layers of scintillation counter and will have 30% efficiency for neutron. The area of the counter is 30cm by 30 cm and the acceptance is $\delta\theta$ is 1°.

Figure 5 shows a schematic view of the gamma counter which consists of CsI crystal and is used at KEK E246 experiment. The read out of the detector will be upgraded for a new T-violation experiment at J-PARC. The detector has 12 acceptance holes for T-violation experiment, however, it's coverage is 75 %.

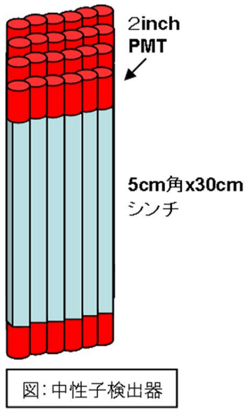

Figure 4: Schematic view of neutron counter

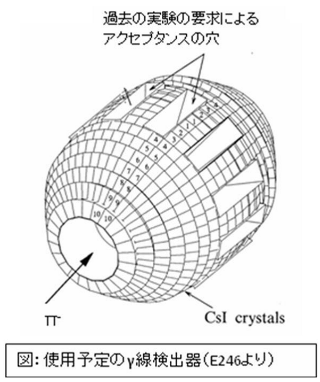

Figure 5: Schematic view of gamma detector

Figure 6 shows invariant mass plot of ω meson smeared by energy resolution of gamma detector. Top and bottom figures are for different energy resolution. According to the calculation, δE/E = 3%/$sqrtE$ is required. Above gamma detecotr has δE/E = 2.8% at 200 MeV [15] and it will be enough.

Obtained ω yield is briefly estimated with measured cross section. in p(π^-, n)ω reaction [16]. Figure 7 shows a summary plot of cross sections of backward ω production as a function of $\sqrt{s}$ in [17]. The production cross section of 0.14 mb/sr is used for the estimation. Thickness of 1 cm of Carbon-12 is chosen as a target and the estimated yield is ~9000 per 100 shifts.

Another issue is final state interaction of π^0. It is evaluated for TAPS experiment [18]. According to this calculation, when π^0 is scattered in nucleus, mass distribution of ω have very large shift in lower side and the effect

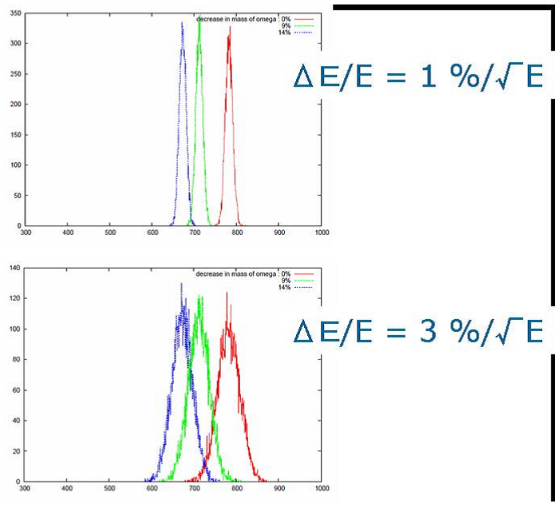

Figure 6: Invariant mass plot of ω meson smeared by energy resolution of gamma detector. Three lines represent ω mass shift =0, 9%, 14%. 9% and 14% are measured value at KEK-E325 and TAPS. Top and bottom figures are for different energy resolution.

is negligible in interested mass region, i.e. just below ω mass.

Trigger and evaluation of background are should be considered for proposal stage. Trigger is a coincidence of 3 γ's and forward neutron. Main background in 3 γ's measurements is 2 π^0 decays and 1 γ missing. 2 π^0 production cross section is measured and background will be estimated upon a measured cross section.

4 Summary

we propose combined measurements of nuclear ω bound state and direct ω mass modification. Nuclear ω bound states are measured in p(π^-, n)ω reaction and decays of generated ω meson are also measured with $\omega \to \pi^0\gamma$ mode. Such exclusive measurement can supply essential information to establish partial restoration of the chiral symmetry in nucleus.

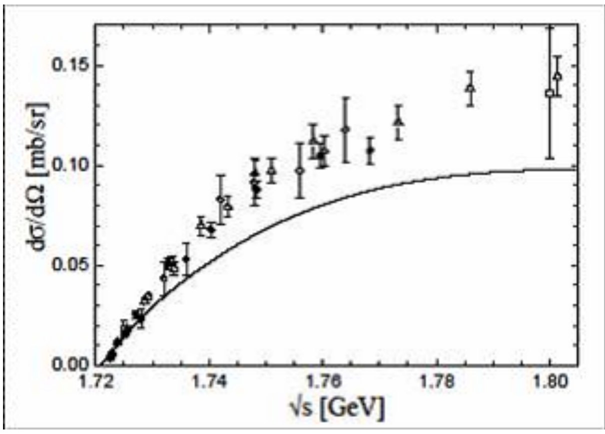

Figure 7: summary plot of cross sections of backward ω production as a function of $\sqrt{s}$ in [17]

References

[1] T. Hatsuda and T. Kunihiro, Phys. Rep. **247** (1994) 221.
G.E. Brown and M. Rho, Phys. Rep. **269** (1996) 333.
W. Cassing and E.L. Bratkovskaya, Phys. Rep. **308** (1999) 65.

[2] K. Suzuki *et al.* , Phys. Rev. Lett **92** (2004) 072302.

[3] K. Ozawa *et al.* , Phys. Rev. Lett **86** (2001) 5019.
M. Naruki *et al.* , Phys. Rev. Lett **96** (2006) 092301.
R. Muto *et al.* , Phys. Rev. Lett **98** (2007) 042501.

[4] M.A. Kagarlis *et al.* , Phys. Rev. **D60** (1999) 025203.
G.M. Huber *et al.* , Phys. Rev. **C68** (2003) 065202.

[5] D. Trnka *et al.* , Phys. Rev. Lett. **94** (2005) 192303.

[6] C. Djalali *et al.* , J. Phys. **G34** (2007) S495.

[7] T. Hatsuda and S.H. Lee, Phys. Rev. **C46** (1992) R34.

[8] F. Klingl, N. Kaiser and W. Weise, Nucl. Phys. **A624** (1997) 527.
F. Klingl, N. Waas and W. Weise, Nucl. Phys. **A650** (1999) 299.

[9] M.F.M. Lutz, Gy. Wolf and B. Friman, Nucl. Phys. **A706** (2002) 431.

[10] P. Muehlich *et al.* , Nucl. Phys. **A780** (2006) 187.

[11] E. Marco and W. Weise, Phys. Lett **B502** (2001) 59.

[12] H. Nagahiro *et al.* , Nucl. Phys. **A761** (2005) 92.

[13] M. Kaskulov *et al.* , Phys. Rev. **C75** (2007) 064616.

[14] H. Kurasawa and T. Suzuki, Prog. Theor. Phys. **84** (1990) 1030.
H. C. Jean, J. Piekarewicz and A. G. Williams, Phys. Rev. **C49** (1994) 1981.
K. Saito, K. Tsushima, A. W. Thomas and A. G. Williams, Phys. Lett. **B433** (1998) 243.
K. Tsushima, D. H. Lu, A. W. Thomas and K. Saito, Phys. Lett. **B443** (1998) 26.
B. Friman, Acta Phys. Polon. **B29** (1998) 3195.
M. Post and U. Mosel, Nucl. Phys. **A688** (2001) 808.
K. Saito, K. Tsushima, D. H. Lu and A. W. Thomas, Phys. Rev. **C59** (1999) 1203.
G. I. Lykasov, W. Cassing, A. Sibirtsev and M. V. Rzyanin, Eur. Phys. J. **A6** (1999) 71.
A. Sibirtsev, C. Elster and J. Speth, nucl-th/0203044.
A. K. Dutt-Mazumder, R. Hofmann and M. Pospelov, Phys. Rev. **C63** (2001) 015204.
M. F. M. Lutz, G. Wolf and B. Friman, Nucl. Phys. **A706** (2002) 431 [Erratum-ibid. **A765** (2006) 431].
S. Zschocke, O. P. Pavlenko and B. Kampfer, Phys. Lett. **B562** (2003) 57.
A. K. Dutt-Mazumder, Nucl. Phys. **A713** (2003) 119.
P. Muhlich, T. Falter and U. Mosel, Eur. Phys. J. **A20** (2004) 499.
P. Muehlich, V. Shklyar, S. Leupold, U. Mosel and M. Post, nucl-th/0607061.
P. Muhlich and U. Mosel, Nucl. Phys. **A773** (2006) 156.
B. Steinmueller and S. Leupold, hep-ph/0604054

[15] D.V. Dementyev *et al.* , Nucl. Instrum. Meth. **A440** (2000) 151.

[16] J. Keyne *et al.* , Phys. Rev. **D14** (1976) 28.

[17] G. Penner and U. Mosel, nucl-th/0111024.

[18] J.G. Messchendorp, A. Sibirtsev, W. Cassing, V. Metag, and S. Schandmand, Eur. Phys. J. **A11**, 95-103 (2001))