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Missing Mass Spectroscopy of η' Mesic Nuclei with the (p,d) Reaction at GSI

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Abstract. We plan a missing-mass spectroscopy experiment of η' mesic nuclei with the ^{12}C(p,d)$\eta' \otimes ^{11}$C reaction to study in-medium properties of the η' meson. In nuclear medium, due to restoration of chiral symmetry, the mass of the η' meson may be reduced, and η' bound states in a nucleus may exist. The experiment will be started at GSI with a 2.5 GeV proton beam using FRS as a spectrometer and will be continued at Super-FRS at FAIR. The plan of the experiment and development of a Cherenkov detector and an optics mode are described.

1 Introduction

The η' meson has a peculiarly large mass among the light pseudoscalar mesons. This is theoretically understood as a consequence of the $U_A(1)$ anomaly effect in combination with a non-vanishing chiral condensate $\langle \bar{q}q \rangle$ and explicit chiral symmetry breaking in the low energy region of QCD [1, 2]. In the nuclear medium, where chiral symmetry is partially restored, the mass of the η' meson may decrease. According to Nambu–Jona-Lasinio (NJL) model calculations, the η' mass at normal nuclear density is reduced by about 150 MeV/c^2 [3, 4]. Such a large mass reduction implies a strong attractive potential between η' and a nucleus, and η' meson-nucleus bound states (η' mesic nuclei) may exist [4–6].

One of the necessary conditions to observe such bound states experimentally is a small in-medium width compared to the mass reduction. The CBELSA/TAPS collaboration reported that the absorption width of the η' meson at the nuclear saturation density is around 15 – 25 MeV for the average η' momentum at 1050 MeV/c [7]. This implies that the decay width of η' mesic nuclei could be small as well, and they may be observed as narrow peaks experimentally.

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2 Experimental plan

We are planning an experimental search for η' mesic nuclei by missing-mass spectroscopy of the ^{12}C$(p,d)\eta' \otimes {}^{11}$C reaction at GSI [8, 9]. A 2.5 GeV proton beam with the rate of 10^{10}/s extracted from the Heavy Ion Synchrotron (SIS) will be injected to a 4 g/cm^2-thick ^{12}C target. We will measure the momentum of the ejectile deuteron using the Fragment Separator (FRS) as a high-resolution spectrometer. The setup of detectors at FRS is shown in Fig. 1. Two sets of multi-wire drift chambers (MWDCs) will be installed at the final focal plane (S4). The momentum of the ejectile deuteron will be derived by measuring the track with MWDCs. The overall missing-mass resolution will be about 1.6 MeV/c^2, which is sufficiently smaller than the expected decay width of η' mesic nuclei.

In addition to the signal deuterons, a large amount of background protons produced by the (p,p') reaction are expected to reach the S4 focal plane at a rate of about 50 kHz. An aerogel Cherenkov counter will be used at the trigger level to reject the proton background based on the velocity difference between the deuteron and the proton. In the offline analysis, the time of flight between S3 and S4 measured by two plastic scintillation counters will be also used for particle identification, and we expect that almost all the background protons can be rejected.

One feature of this experiment is an inclusive measurement. This leads to a straightforward and unbiased analysis of the spectrum because no assumption on decay processes of η' mesic nuclei is necessary. The signal-to-noise ratio will become very small due to background processes such as multi-pion production ($p + n \to d + \pi$'s). Therefore, a high statistics measurement is essential using an intense primary beam and a thick production target. Figure 2 shows simulated inclusive spectra for several in-medium mass reductions and widths [9]. The η'-nucleus optical potential is parametrized as $V(r) = (V_0 + iW_0)\rho(r)/\rho_0$, where ρ_0 is the normal nuclear density. If the mass reduction is large and the width is small, peak structures can be observed. If $V_0 = -150$ MeV, as predicted by the NJL model calculations [3,4], and $|W_0|$ is less than 12.5 MeV, as indicated by the CBELSA/TAPS experiment [7], peak structures will be observed experimentally in the missing-mass spectrum.

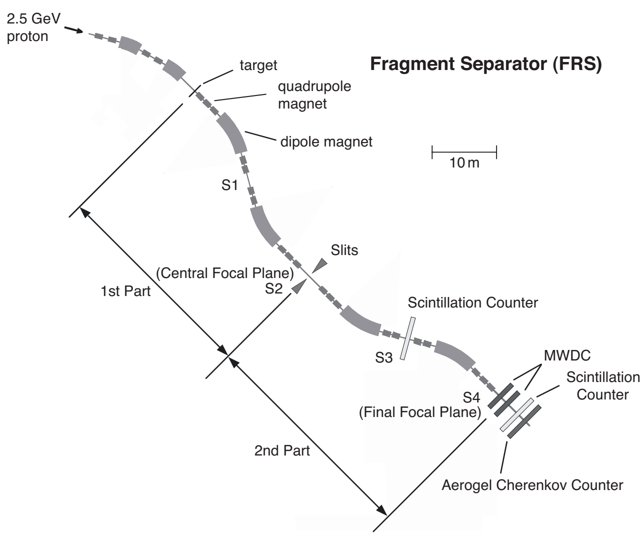

Figure 1. An overview of the detector setup at FRS. MWDCs and an aerogel Cherenkov counter will be installed at S4. Plastic scintillation counters will be placed at S3 and S4.

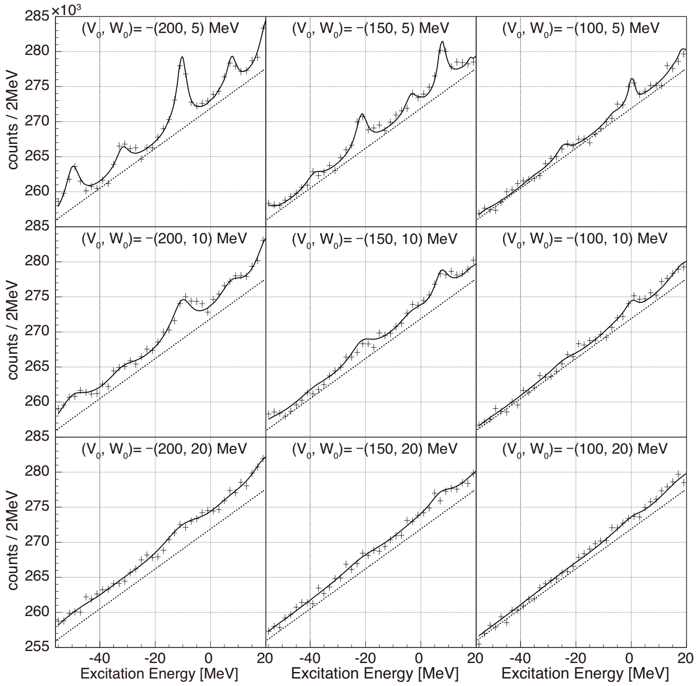

Figure 2. Simulated inclusive spectra for several in-medium mass reductions and widths expected in 4.5-day data acquisition with 3.24×10^{14} primary protons on a 4 g/cm^2-thick ^{12}C target. The horizontal axis is the excitation energy of the $\eta' \otimes {}^{11}$C system with the mass of the free η' meson subtracted. The dashed lines show the amount of the background processes.

3 Development of a Cherenkov counter and an ion-optical system

We have developed a high-refractive-index aerogel Cherenkov counter for particle identification at the hardware level. A silica aerogel with a refractive index of 1.18 [10] is adopted as a Cherenkov radiator in order to distinguish the signal deuterons ($\beta \sim 0.83$) from the background protons ($\beta \sim 0.95$). The detector was tested at GSI using deuteron beams of two velocities, $\beta = 0.84$ and 0.94. The solid line and the dashed line in Fig. 3 show the observed photoelectron spectrum for the higher velocity and for the lower velocity, respectively. Sufficient rejection capability for the higher velocity has been achieved with a few percent overkill for the lower velocity .

We have been developing a new ion optics of FRS. In order to use the first half of FRS for suppressing secondary background produced by a dumped primary beam and the second half for the momentum analysis with MWDCs, an ion-optical system with achromatic focusing at the central focal plane (S2) and dispersive focusing at S4 is necessary. Figure 4 shows a preliminary optics mode. This mode keeps small dispersion throughout the whole system providing a large momentum acceptance of about 4%, which corresponds to 100 MeV in excitation energy.

4 Summary and future prospect

We are planning an experimental search for η' mesic nuclei by missing-mass spectroscopy of the ^{12}C$(p,d)\eta' \otimes {}^{11}$C reaction. The experiment will be carried out at GSI with a 2.5 GeV proton beam from

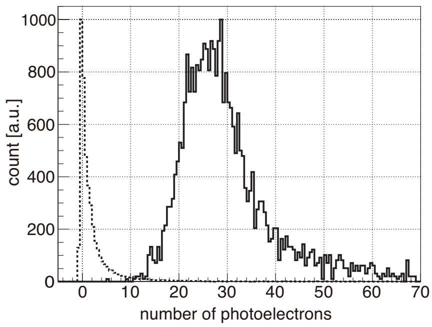

Figure 3. Histograms of the total number of photoelectrons observed by the aerogel Cherenkov counter. The solid line is for the higher velocity, $\beta = 0.94$, and the dashed line is for the lower velocity, $\beta = 0.84$.

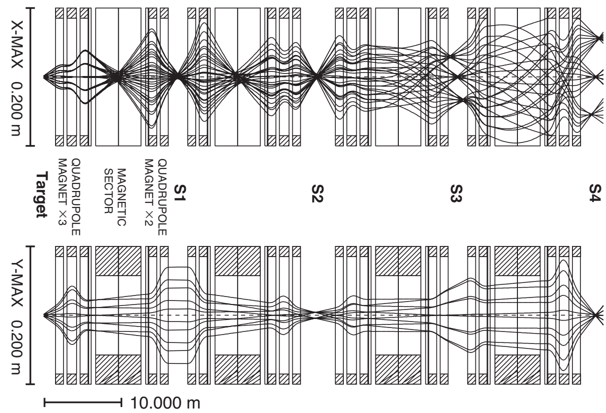

Figure 4. A newly developed optics mode of FRS calculated with up to third order transfer matrices. The upper plot indicates horizontal direction, and the lower plot indicates vertical direction. Beam trajectories are shown for momentum deviations of ±1.5% and for beam ellipses at the target position of 1.5 mm × 8 mrad for both horizontal and vertical directions.

SIS and with FRS used as a high-resolution spectrometer. If the η' meson has a sufficiently large mass reduction and a small decay width at normal nuclear density, peak structures may be observed even in an inclusive spectrum.

The first pilot experiment is expected in 2014, and the preparation is presently on-going. A high-refractive-index aerogel Cherenkov detector for the on-line particle identification and a new ion optics for FRS have been developed.

In the future, we plan a semi-exclusive measurement of the (p,dp) reaction at FAIR [11]. In order to improve the signal-to-noise ratio, we will tag protons from the decay of η' mesic nuclei in addition to the missing-mass measurement with Super-FRS. R&D of the proton tagging system is in progress.

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References

[1] D. Jido, H. Nagahiro, and S. Hirenzaki, Phys. Rev. C **85**, 032201(R) (2012).
[2] S. H. Lee and T. Hatsuda, Phys. Rev. D **54**, 1871 (1996).
[3] P. Costa, M. C. Ruivo, and Yu. L. Kalinovsky, Phys. Lett. B **560**, 171 (2003).
[4] H. Nagahiro, M. Takizawa, and S. Hirenzaki, Phys. Rev. C **74**, 045203 (2006).
[5] H. Nagahiro and S. Hirenzaki, Phys. Rev. Lett. **94**, 232503 (2005).
[6] H. Nagahiro *et al.*, Phys. Rev. C **87**, 045201 (2013).
[7] M. Nanova *et al.*, Phys. Lett. B **710**, 600 (2012).
[8] K. Itahashi *et al.*, Letter of Intent for GSI-SIS (2011).
[9] K. Itahashi *et al.*, Prog. Theor. Phys. **128**, 601 (2012).
[10] M. Tabata *et al.*, Nucl. Instr. Meth. A **623**, 339 (2010).
[11] H. Fujioka *et al.*, in these proceedings.