Spectroscopy of $\eta'$ Mesic Nuclei with $(p,d)$ Reaction

Kenta Itahashi, Helmut Weick
RIKEN Nishina Center, GSI
Summary

Missing mass spectroscopy by \((p,d)\) reaction to study \(\eta'\) meson bound states

\(\eta\) meson bound states

\((V_0', W_0) = (150, 5)\) MeV

Summary
η' Meson

Pseudo scalar meson (J^{\pi}=0^-)

M = 958 MeV/c^2

Γ = 0.199 MeV

Decay: π^+π^-η (43%), ργ (29%), π^0π^0η (22%)
η’ and other PS mesons

η’ \( M = 958 \text{ MeV/c}^2 \)

η \( M = 548 \text{ MeV/c}^2 \)

K \( M = 498 \text{ MeV/c}^2 \)

π \( M = 140 \text{ MeV/c}^2 \)

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η' and other PS mesons

η'
M = 958 MeV/c²

π
M = 140 MeV/c²

η problem

\( m_{\eta'} < \sqrt{3} m_\pi \)
(Weinberg, 1975)
Large $\eta'$ mass can be explained

$U_\Lambda(1)$ symmetry breaking term of effective Lagrangian

\[ \langle \bar{q} q \rangle \]

6-point vertex

Kobayashi-Maskawa-'t Hooft-type interaction

Kobayashi, Maskawa, PTP44(70)1422
\‘t Hooft, PRD14(76)3432.
Klimt, Lutz, Vogl, Weise, NPA516(90)429.
η’ Meson

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\( \eta' \) in medium
Chiral Condensate in Finite T/\rho

W. Weise, NPA553(93)59.
Chiral Symmetry and Pionic Atoms

Order parameter of Chiral symmetry $\langle qq \rangle$

$|\langle qq \rangle|$

$\sim 30\%$

normal nuclear density

300 MeV

Chiral symmetry fully restored

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$\eta'$ in-medium

Naive estimation shows 30% reduction of $|m_{\eta'} - m_\eta|$

Q. Mass shift of $\sim 140$ MeV/c$^2$ can be observed in experiment?

Jido, Nagahiro, Hirenzaki, arxiv 1109.0394
Experimental spectroscopy of η’ mesic nuclei
η’ Mesic Nuclei in \((p,d)\) Reaction

η’ transfer reaction + Missing mass measurement

\[ T_p = 2.50 \text{ GeV} \rightarrow q \sim 400 \text{ MeV/c} \]
Theoretical Prediction

η’-nucleus potential:

\[ V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0} \]

- \( \rho \): nucleon density
- \( V_0 \): Real potential depth
- \( W_0 \): Imaginary potential depth

\[ ^{12}\text{C}(p,d) \text{ at } T_p = 2.50 \text{ GeV} \]

Nagahiro, Hirenzaki, Jido, private communication

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Bound states

(0p_{3/2})_n \otimes \pi_{\eta'}
(0p_{3/2})_n \otimes \eta_{\eta'}
(0p_{1/2})_n \otimes s_{\eta'}
(p_{3/2})_n \otimes f_{\eta'}
(p_{3/2})_n \otimes g_{\eta'}
(p_{3/2})_n \otimes d_{\eta'}

Nagahiro, Hirenzaki, Jido, private communication

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Experimental Setup

2.5 GeV proton

$I_p = 10^{10}$/spill
4 g/cm$^2$ $^{12}$C target

Tracking = 2 x MWDC
PiD = 2 x Scintillator + Aerogel Cerenkov

$T_d = 1.37$~$1.66$ GeV
$P_d = 2.65$~$3.00$ GeV/c
$\beta_d = 0.816$~$0.848$
$\beta_p = 0.962$

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Experimental Setup

2.5 GeV proton

1_p = 10^{10}/spill
4 g/cm^2 \text{^{12}C} target

FRS is the key for good resolution and bk rejection

Estimated maximum proton rate \sim 60 \text{kHz}
trigger rate = 1 \text{kHz}

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Expected Spectra

\[ V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0} \]

\( \rho \): nucleon density
\( V_0 \): Real potential depth
\( W_0 \): Imaginary potential depth

(\( V_0', W_0 \)=-(100, 20) MeV)

(\( V_0', W_0 \)=-(150, 5) MeV)

in 4.5 days DAQ
Structure-finding Probability

\[ V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0} \]

in 4.5 days DAQ for 95% C.L.
Structure-finding Probability

\[ V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0} \]

Disfavored by CB-ELSA transparency measurement.
(Nanova et al., Hadron2011)

in 4.5 days DAQ for 95 % C.L.

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Presented as Loi to GPAC last week, but with request for 3 day test beam time

We aim at

✓ Measurement of cross section levels of signal + background
✓ Test of new beam optics
✓ Detector system integrity check + overall test
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New Beam Optics

FRS with Unique Background Rejection Capability

Horizontal

TA-S2 0.3 cm/%
TA-S4 5.5 cm/%

Vertical
Particle Identification

Aerogel (n=1.12)

Fine tuning will enable adoption of TOF based hardware trigger

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Chances in 3-Day Beamtime

\[ V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0} \]

\( \rho \): nucleon density
\( V_0 \): Real potential depth
\( W_0 \): Imaginary potential depth

(\( V_0, W_0 \) = -(150, 5) MeV)

We have chances to observe peaks in 1-day.
Summary

• Spectroscopy of in-medium $\eta'$ is in preparation.

• We set ambitious goals to understand fundamental symmetry of vacuum and QCD.

• Experiment is possible only in GSI.

• 3-day preceding beamtime is requested to figure out crucial parameters for the experiment. We even have chances to observe peaks in the 3 days.
Collaboration

K. Itahashi1, H. Outa,
Nishina Center for Accelerator-Based Science, RIKEN, 2-1 Hirosawa, Wako, 351-0198 Saitama, Japan

H. Fujioka2,
Division of Physics and Astronomy, Kyoto University, Kitashirakawa-Oiwakecho, Sakyoku, 606-8502 Kyoto, Japan

H. Geissel, H. Weick3,
GSI - Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany

V. Metag, M. Nanova,
II. Physikalisches Institut, Universität Gießen, D-35392 Gießen, Germany

Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-0033 Tokyo, Japan

S. Hirenzaki, H. Nagahiro,
Department of Physics, Nara Women’s University, Kita-Uoya Nishi-Machi, 630-8506 Nara, Japan

D. Jido,
Yukawa Institute for Theoretical Physics, Kyoto University, Kitasirakawa-Oiwakecho, Sakyoku, 606-8502 Kyoto, Japan

and K. Suzuki, E. Widmann
Stefan Meyer Institut für subatomare Physik, Boltzmangasse 3, 1090 Vienna, Austria