In-medium Properties of $\eta'$ Mesons

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outline

❖ motivation
❖ experimental setup
❖ reconstruction of the η’ meson
❖ η’ production on proton and on deuteron
❖ η’ production on nuclei
  - experimental approaches for studying the in-medium properties of η’ meson
  - transparency ratio ($T_A$) measurements
  - comparison with the $T_A$ of other mesons
❖ summary & outlook
masses as a result of symmetry breaking
predicted in-medium properties of the $\eta'$ meson


mass changes of $\eta$ and $\eta'$ mesons in the nuclear medium

existence of $\eta'$ mesic states

$U(r) = V(r) - iW(r)$;
$V(r) = \Delta m(\rho_0) \cdot \rho(r)/\rho_0$

$^{12}\text{C}(\gamma,p)\eta' \ @ \ E_\gamma = 2.7 \text{ GeV}$

possible observation of the $\eta'$-mesic nucleus!
population of mesic states in photonuclear reaction


\(^{12}\text{C}(\gamma,p)\eta,\omega,\eta' \; @ \; E_\gamma = 2.7 \text{ GeV}\)

(a): \(g_D(\rho)=g_D\)
\(V(r=0)=\Delta m=-150 \text{ MeV}\)

(b): \(g_D=0\)
\(V(r=0)=\Delta m=0\)

(c): \(g_D(\rho)=g_D \cdot \exp[-(\rho/\rho_0)^2]\)
\(V(r=0)=\Delta m=-270 \text{ MeV}\)
Crystal Barrel/TAPS@ELSA Experiment

http://www.cb.uni-bonn.de

Photon beam

$E_\gamma = 0.5 - 2.6$ GeV

Crystal Barrel: 1290 CsI

SciFi Detector

TAPS: 528 BaF$_2$

4$\pi$ photon detector
identification of the $\eta'$ signal


$\eta' \rightarrow \pi^0 \pi^0 \eta \rightarrow 6\gamma$  
BR: 8.1%

- selection of events with 6 neutral and 1 charged particle
- kinematic fitting - constraints: $(E,p)$ conservation
- combination of 2 $\gamma\gamma$ pairs with $110$ MeV $< m_{\gamma\gamma} < 160$ MeV
  and 1 $\gamma\gamma$ pair 500 with MeV $< m_{\gamma\gamma} < 600$ MeV

$\gamma p \rightarrow \pi^0 \eta \gamma \gamma$

$\gamma p \rightarrow \pi^0 \pi^0 \gamma \gamma$

$\eta'$ signal
photoproduction of $\eta'$ meson on the proton

$\eta$ and $\eta'$ offer additional selectivity to $N^*$ resonances (isospin filter)

flat angular distributions near production threshold ($E_\gamma=1443$ MeV) → s-wave dominated

total cross section determined - exploiting full angular coverage, no extrapolation needed
photoproduction of $\eta'$ meson on the deuteron


angular distributions for quasi-free $\gamma n \rightarrow \eta' n$

--- $\eta'$-MAID model
W.T. Chiang et al.,
PRC 68 (2003) 045202
$P_{11}, P_{13} (1950\,\text{MeV}), D_{13}$

NH model
K. Nakayama, H. Haberzettl,
PRC 73 (2006) 045211,
PRC 69 (2004) 065212
— solution I
$S_{11}(1958), P_{11}(2104), P_{13}(1885), D_{13}(1823)$
... solution Ia
additional $S_{11}$

measurements of polarization observables needed!
photoproduction of $\eta'$ mesons on nuclei

$\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$ \quad BR: 8.1% \quad CB/TAPS@ELSA

- solid targets: $^{12}$C, $^{40}$Ca, $^{93}$Nb and $^{208}$Pb
- event selection: $\geq 6$ neutral particles AND/OR 6n + 1ch
- sum energy of 6 neutral particles $> 600$ MeV
- competing channel with same final state: $\eta \rightarrow \pi^0\pi^0\pi^0 \rightarrow 6\gamma$
  reconstructed and removed in further analysis

- C
- 115 000 counts
- $\sigma = 10.51 \pm 0.06$ MeV
- $m = 547.6 \pm 0.1$ MeV
photoproduction of $\eta'$ mesons on nuclei ($E_\gamma=1200-2200$ MeV)

$$\gamma A \rightarrow \eta' A' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma A'$$

$A=C, \ Ca, \ Nb, \ Pb$

### C
- 400 counts
- $\sigma=8.2\pm1.0$ MeV
- $m=956.2\pm0.9$ MeV

### Ca
- 320 counts
- $\sigma=12.4\pm1.7$ MeV
- $m=956.1\pm1.5$ MeV

### Nb
- 540 counts
- $\sigma=10.5\pm1.0$ MeV
- $m=956.8\pm0.9$ MeV

### Pb
- 160 counts
- $\sigma=12.3\pm2.3$ MeV
- $m=956.9\pm1.8$ MeV
How to study in-medium properties of the \( \eta' \) meson?

- **line shape analysis:** not applicable;
  \( \eta' \) meson decays outside of nucleus;
  \( M_0 = 957.78 \text{ MeV} \); \( \Gamma_0 = 0.194 \text{ MeV} \);
  \( \lambda_{\text{dec}} = \frac{\hbar c}{\Gamma_0} = 1000 \text{ fm} \gg R_{\text{nucl}} \)

- **in-medium width?**
  attenuation measurement of the \( \eta' \) meson flux

  **transparency ratio:**
  \[
  T_A = \frac{\sigma_{\gamma A \rightarrow \eta'X}}{A \cdot \sigma_{\gamma N \rightarrow \eta'X}}
  \]
  measure for the loss of meson flux through inelastic processes in the nucleus

  experimental observable to extract the in-medium width of the meson
in-medium width of the $\eta'$ meson

in the medium $\eta' = \text{quasi-particle}$; properties reflect interaction with the medium; additional inelastic channels remove $\eta'$-mesons, e.g. $\eta' N \rightarrow \pi N$

$\Rightarrow$ shortening of $\eta'$-lifetime; increase in width

in-medium $\eta'$ inelastic width proportional to $\eta'$ absorption: $\Gamma(\rho, |p_{\eta'}|) \propto \rho \nu \sigma_{\text{abs}}$

transparency ratio:

$$T_A = \frac{12 \cdot \sigma_{\gamma A \rightarrow \eta' X}}{A \cdot \sigma_{\gamma C \rightarrow \eta' X}}$$

normalized to C

comparison with $T_A$ for $\omega$ meson

$\Gamma(\rho_0, <|\omega|> \approx 1.1 \text{ GeV/c}) \approx 130-150 \text{ MeV}$

M. Kotulla et al. PRL 100 (2008) 192302

$\eta'$ absorption weaker than $\omega$ absorption!!

but how large is the width??

$\Rightarrow$ comparison to transport model calculations

$E_\gamma = 1200-2200 \text{ MeV}$

$\eta'$

$\omega$ PRL 100 (2008) 192302
in-medium properties of the \( \eta' \) meson

\( \eta' \) yields for Nb and Pb targets in 3 different incident photon energy ranges

**Nb 1200-1800 MeV**

- 230 counts
- \( \sigma = 9.4 \pm 2.1 \) MeV
- \( m = 956.9 \pm 1.1 \) MeV

**Nb 1800-2000 MeV**

- 124 counts
- \( \sigma = 11.6 \pm 2.5 \) MeV
- \( m = 954.8 \pm 2.8 \) MeV

**Nb 2000-2200 MeV**

- 110 counts
- \( \sigma = 8.4 \pm 1.5 \) MeV
- \( m = 956.7 \pm 1.1 \) MeV

**Pb 1200-1800 MeV**

- 60 counts
- \( \sigma = 11.1 \pm 2.3 \) MeV
- \( m = 958.0 \pm 2.3 \) MeV

**Pb 1800-2000 MeV**

- 40 counts
- \( \sigma = 8.2 \pm 3.3 \) MeV
- \( m = 957.2 \pm 3.4 \) MeV

**Pb 2000-2200 MeV**

- 40 counts
- \( \sigma = 8.3 \pm 2.1 \) MeV
- \( m = 956.9 \pm 2.2 \) MeV
\( \eta' \) in-medium width and absorption cross section

\( \eta' \) transparency ratio compared with theoretical calculations by A. Ramos and E. Oset

\[
T_A = \frac{12 \cdot \sigma_{\gamma A \to \eta' X}}{A \cdot \sigma_{\gamma C \to \eta' X}}
\]

Comparison to data \( \Gamma(\rho_0, <|p_{\eta'}|>) \approx 0.9 \text{ GeV/c} \approx 25-30 \text{ MeV} \)

Absorption cross section:

\[
\sigma_{\eta' N} = \frac{\Gamma_{inel}}{\rho \cdot \beta \cdot \hbar \cdot c} \approx 14 \text{ mb}
\]
**Problem:** absorption measurement distorted by two-step production processes like: $\gamma N \rightarrow \pi N$, $\pi N \rightarrow \omega N$ or $\pi N \rightarrow \eta' N$?

\[ T_A = \frac{12 \cdot \sigma_{\gamma A \rightarrow \eta' X}}{A \cdot \sigma_{\gamma C \rightarrow \eta' X}} \]

*T. Mertens et al., EPJA 38 (2008) 195*

Two-step processes suppressed by $T_{\eta >} (E_{\gamma} - m_{\eta})/2$

$T_A$ measurement for $\eta$ meson strongly affected by two-step processes; only little effect for $\eta'$ and $\omega$ mesons
interaction of mesons in nuclear medium

A-scaling of production cross sections as a function of the meson kinetic energy

$$\sigma(A) = \sigma_0 \cdot A^{\alpha(T)}$$

- $\alpha \approx 1.0$: mesons escape from the full volume
- $\alpha \approx 2/3$: mesons escape only from the surface

$\pi^0$ mesons:
- low energies: only very weak interaction;
- strong absorption for higher energies: resonance excitation

$\eta$ mesons:
- strong absorption for all $T$

$\omega$ mesons:
- strong absorption: $\langle \alpha \rangle_T \approx 0.67$

$\eta'$ mesons:
- $\langle \alpha \rangle_T \approx 0.84$
- $\eta'N$ interaction weaker than $\eta N$


$M. Nanova et al. to be published$
Preliminary results about the in-medium properties of $\eta'$ meson:

- Transparency ratio measurement:
  - In-medium width 25-30 MeV at $p_{\eta'} = 0.9$ GeV/c
  - $\sigma_{\eta'N} \approx 14$ mb

- Secondary production suppressed by cut on kinetic energy of meson

- Cross section measurement $\sigma_A = \sigma_0 \cdot A^\alpha$:
  - $<\alpha>_T = 0.84$ - indication for weaker interaction in nuclear medium compared to $\eta$ and $\omega$
data taken with the new (improved) version of CB/TAPS detector @ ELSA
with $^{12}$C target - beamtime 2009:
- searching for $\omega$ - bound states (S. Friedrich)

$$E_\gamma \text{ max } 2.9 \text{ GeV}$$

H. Nagahiro, M. Takizawa and S. Hirenzaki,

...and for
- $\eta'$ - bound states

Thank You!