Photoabsorption and Photoproduction on Nuclei in the Resonance Region

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Hadron Physics

- Why are quarks confined within hadrons?
- How are hadrons constructed from their constituents?
- What is the relation of parton degrees of freedom and the low energy structure of hadrons?
- Do glueballs (ggg) and hybrids (qqg) exist?
- What is the origin of hadron masses?
- How are hadrons modified when embedded in nuclei?
- What is the role of chiral symmetry?
Excited States of the Nucleon

- broad and overlapping resonances
- characteristic meson decay
- tagging of resonances

Photoabsorption on Nucleons

\[ \gamma + p \]
from \( \gamma + d \)

\[ \gamma + p \]

\[ \gamma + d \]

N. Bianchi et al. PRC 54 (1996) 1688
Meson Photoproduction from the Proton

partly preliminary!

SAPHIR (Bonn)
CBELSA (Bonn)
DAPHNE, TAPS (Mainz)
GRAAL (Grenoble)

\[ \pi^0 \]
\[ \pi^+ \]
\[ \pi^+ \pi^- \]
\[ \pi^+ \pi^0 \]
\[ \pi^0 \pi^0 \]
\[ \eta \]
\[ \omega \]
\[ K^+ \Lambda \]
\[ K^+ \Sigma^0 \]
\[ K^0 \Sigma \]
\[ \phi \]
Nuclear Photoabsorption: $\gamma + A$

total cross section per nucleon

V. Muccifora et al., PRC 60 (1999) 064616

- evidence for medium modification: no resonance structures above 0.6 GeV

- $D_{13} \rightarrow N\rho$ decay branch
  Mosel et al.

- modified $\pi\pi$ interaction/interferences
  Hirata et al.
  Oset et al.

$\rightarrow$ resonance broadening in medium?

study meson production
(quasifree production)
**ρ Meson in the Nuclear Medium**

*W. Peters et al., NPA 632 (1998) 109*

**Prediction:**
- In-medium broadening of ρ meson
- Coupling to $D_{13} (1520)$

**Effect on Photoabsorption:**
- Modified $D_{13} \rightarrow N \rho$ width
- Depletion of 2. resonance region possible

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**Graphs:**
- Plot showing the effect of varying momentum on the ρ meson's mass in the nuclear medium.
- Plot showing the photoabsorption cross-section with different potential models.
• cooperative effect of the interference in two-pion photoproduction processes
• collision broadening of $\Delta$ and $N^*(1520)$
• pion distortion in the nuclear medium

the change of the interference effect by the medium plays an important role
Medium Effects

on baryon resonances:

- Fermi-motion \( \Gamma \uparrow \)
- meson decay \( \Gamma \downarrow \)
  \( N^* \rightarrow N + \text{meson} \) (Pauli blocking)
- collisional broadening \( \Gamma \uparrow \)
  \( N^*N \rightarrow N^*N \)
- quenching reduction of meson yield
  \( N^*N \rightarrow NN \)
- \( N^* \)-propagation mass / width

self energy

investigating the second resonance region:

- comparison of heavier nuclei with deuteron
- resonance contribution qualitatively not changed
  no indication for broadening or depletion

on mesons:

- absorption/rescattering
- modified meson-meson interaction
- chiral symmetry restoration
- meson-resonance coupling
Meson Photoproduction from the Proton

\[
\text{sum } \pi + \pi \pi + \eta
\]

Meson Photoproduction from Nuclei

\[
\text{sum } \pi^0 + \pi^0 \pi + \eta
\]

- \( \sigma(\text{mb}) \)
- \( E_\gamma(\text{GeV}) \)

- \( \sigma/A(\text{mb}) \)
- \( E_\gamma(\text{GeV}) \)

\( \bullet \text{ Photoabsorption } (\alpha = 1) \)
\( \text{Meson Production } \alpha = (2/3) \)

- \( \circ \text{ p, C } (\gamma, \pi^0) \)
- \( \bullet \text{ p, C } (\gamma, \pi^+) \)
- \( \bullet \text{ p, Pb } (\gamma, \pi^+ \pi^0) \)
- \( \circ \text{ p, Pb } (\gamma, \pi^0 \pi^0) \)
- \( \star \text{ p, Pb } (\gamma, \eta) \)

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chiral symmetry = fundamental symmetry of QCD for massless quarks

chiral symmetry broken on hadron level

\( m_N = 938 \text{ MeV} \gg m_q \approx 5 - 10 \text{ MeV} \)
determined by interaction among partons

To understand the origin of mass:
can we (partially) restore chiral symmetry?

changes of hadron properties in the nuclear medium
Model predictions for $\rho$ and $\omega$ mesons

- **T. Renk et al., PRC 66, 014902, 2002**

- **W. Peters et al., NPA 632 (1998) 109**


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**variation in $\omega$-mass due to density dependence of 4 quark condensate**

**hadronic many body effects**

**structure in spectral function due to coupling to baryon resonances**
Experimental Method: 4$\pi$ Photon Spectrometer

ELSA  
$E_e = 3.5 \text{ GeV}$

MAMI-B  
$E_e = 0.82 \text{ GeV}$

MAMI-C  
$E_e = 1.5 \text{ GeV}$

CBELSA/TAPS

Crystal Ball@MAMI/TAPS
ω-mass in nuclei from photonuclear reactions

**Advantage:**
- $\pi^0\gamma$ large branching ratio (8%)
- No $\rho$-contribution ($\rho \rightarrow \pi^0\gamma : 7 \cdot 10^{-4}$)

**Disadvantage:**
- $\pi^0$-rescattering
- Background reactions: $\gamma A \rightarrow 2 \pi^0 + X$
- Mass resolution
\( \gamma + Nb @ 1.2 GeV; \omega \rightarrow \pi^0 \gamma \)

reduce rescattering using cut on kinetic energy of the pion

- suppression of background in the region of interest
- visible shoulder in lineshape from mass shifted mesons
inclusive $\omega \to \pi^0 \gamma$ signal for LH$_2$ and Nb target

D. Trnka et al. PRL (2005) 192303

difference in line shape of $\omega$ signal for proton and nuclear target
contribution from $\omega$ in-medium decays

$\omega$ decays in vacuum removed by subtracting $\omega$ mass distribution measured with LH$_2$ target (75%)

Strength of in-medium $\omega$ decays concentrated around masses of 722 MeV

$\Rightarrow$ mass drop by about 8%

at estimated baryon density of about 0.6 $\rho_0$

consistent with $m_\omega = m_0 (1 - 0.14 \rho/\rho_0)$
vector mesons

- $\rho \rightarrow e^+e^-$ in ultra-relativistic heavy-ion collisions (CERES/CERN)
- $\rho \rightarrow e^+e^-$ in pA collisions at 12 GeV (KEK)
- $\omega \rightarrow \pi^0\gamma$ by comparison of $p(\gamma,\omega)$ and $A(\gamma,\omega)$ (CBELSA/TAPS @ Bonn)
- $\Phi \rightarrow K^+K^-$ systematics from $A(\gamma,\omega)$ (LEPS@SPRing8)
- $\pi^- p \rightarrow n\omega$ on bound protons planned at HADES @ GSI

pseudoscalar mesons

- $K^+$ and $K^-$ mesons from yields in near threshold heavy-ion reactions (KAOS @ GSI)

scalar mesons

- ``$\sigma$' meson: $\pi^0\pi^0$ interaction (TAPS@MAMI, Crystal Ball)

charm sector

- $J/\psi$, $D$: experiments planned at PANDA@FAIR

So far, experiments are in accordance with theoretical scenarios for changes of hadron properties in the nuclear medium.

Studying the in-medium behavior of hadrons is a promising approach to learn more about the origin of their mass.