Properties of Charm Particles in the Nuclear Medium

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Origin of Hadron Masses

\[ 2M_u + M_d \sim 15 \text{ MeV/c}^2 \]
\[ M_p = 938 \text{ MeV/c}^2 \]

Explicit breaking of CS

No low mass hadrons (except \(\pi, K, \eta\))

Spontaneously broken chiral symmetry

(P.Kienle)
Spontaneous Breaking of Chiral Symmetry

Although the QCD Lagrangian is symmetric, the ground state need not be.

Example:

Fig. 14.3 The potential $V(\phi) = \frac{1}{2} \mu^2 \phi^2 + \frac{1}{4} \lambda \phi^4$ for (a) $\mu^2 > 0$ and (b) $\mu^2 < 0$, and $\lambda > 0$. 
Quark Condensate

The QCD vacuum is not empty \[ \langle q\bar{q} \rangle \neq 0 \]

Hadron masses are generated by the strong interaction with \( <qq> \)

The density of the quark condensate will change as a function of temperature and density in nuclei.

This should lead to modifications of the hadron’s spectral properties.
Hadron Production in the Nuclear Medium

Mass of particles may change in dense matter

\[ K^-(s\bar{u}) : \frac{m_s}{m_u} \approx 40 \]
\[ D^+(c\bar{d}) : \frac{m_c}{m_d} \approx 200 \Rightarrow \text{Quark atom} \]
Deeply Bound Pionic Atoms

Pionic capture is possible with the appropriate choice of kinematics:

\[ d + n \rightarrow ^3\text{He} + \pi^- \]

These results indicate a mass shift of \(~25\) MeV for pions at normal nuclear matter density.
Kaons in Nuclear Matter

Kaon and anti-kaon masses should no longer be degenerate in nuclear matter.

Expected signal: increased $K^-$ production compared to $K^+$. 
Measured $K^-$ Cross Section

Comparison of proton-proton data with heavy ion data$^{[2]}$:

![Graph showing comparison of proton-proton data with heavy ion data](Image)


What Can Antiproton Beams Contribute to this Discussion?

Much lower momentum for heavy produced particles (2 GeV for “free”)
(Effects are smaller at high momentum)

Open charm mass region (H atom of QCD) @HESR
(single light quark)

Well defined nuclear environment (T and ρ)
Open Charm in Nuclei

Signal:
strong enhancement of
the D meson cross section
near threshold

$p+A$ is complimentary to
$A+A$, but the density is
known and $T \sim 0$!
Dilepton Measurements

The spectral function of the charmonium state in the nuclear medium can be measured directly with dileptons.
The mass of charmonium states is not expected to change much.

However, a drop of the $D\bar{D}$ mass leads to a widening of the $c\bar{c}$ states.

$\Psi'$ will have too high momentum, most decay outside.

$\rightarrow$ but wider tails
Charmonium in Nuclei

Due to the increased width, the dileptons from charmonium states below the free DD threshold are strongly suppressed.

$J/\Psi$ Absorption in Nuclei

$J/\Psi$ absorption cross section in nuclear matter

$\bar{p} + A \rightarrow J/\Psi + (A-1)$
Strange Baryons in Nuclear Fields

Hypernuclei open a 3\textsuperscript{rd} dimension (strangeness) in the nuclear chart

- New Era: high resolution $\gamma$-spectroscopy
- Double-hypernuclei: very little data
- Baryon-baryon interactions: $\Lambda$-N only short ranged (no $1\pi$ exchange due to isospin) $\Lambda$-$\Lambda$ impossible in scattering reactions

$\bar{p}$
3 GeV/c

secondary target

$\Xi^-$

$\Xi^-(dss)\, p(uud) \Rightarrow \Lambda(uds) \, \Lambda(uds)$
Summary

• Hadron masses are mostly due to their interaction with the QCD vacuum.
• There is evidence for partial restoration of chiral symmetry for pions and kaons.
• Antiproton - Nucleus interactions allow the charm region to be studied at relatively low momentum.
• There is a wide program to measure open charm and dilepton spectroscopy of charmonium states.
• Measurements of absorption cross sections possible.
• (Double hypernuclei)