Medium Modifications of the \( \Delta(1232) \)

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Motivation

Medium modifications of baryons

- role of baryons for dilepton spectra (in-medium modification of vector mesons)
- chiral phase transition
- here: Nucleon and $\Delta$ in hot/dense matter
- Connection JLAB/RHIC physics: photo absorption on nuclei vs. $\pi N$ invariant-mass spectra
Hadronic model in the vacuum

- hadronic fields: N, $\pi$, $\Delta(1232)$, higher resonances
- pions fully relativistic
- baryons: anti-particle poles neglected
- $\pi N \Delta$ vertex: p wave
- $\pi N B^*$ vertices: usually Lowest angular momentum

form factors

$$F_{\text{mono}}(|\vec{k}|) = \frac{\Lambda^2}{(\Lambda^2 + \vec{k}^2)} \quad (s\text{-} \text{and} \ p\text{-}waves)$$

$$F_{\text{dip}}(|\vec{k}|) = \left[\frac{2\Lambda^2}{(2\Lambda^2 + \vec{k}^2)}\right]^2 \quad (d\text{ waves})$$
Hadronic model in the vacuum

\[ \Delta \pi \Delta \rightarrow N \]

\( B^* \Delta/N \pi \) vertex ↔ partial decay widths

e.g. \( N^*(1440) \) (s wave), \( N^*(1520) \) (s+d waves), \ldots

**\( \pi N \) scattering phase shift**

- Model fit
  - \( f_{\pi\Delta} = 3.3 \), \( \Lambda_{\pi} = 290 \text{ MeV} \)
- Data (Arndt et al)

\[ \delta_{33} [\text{deg}] \]

\[ \left[ \text{GeV} \right] \]
Medium Modifications of pions

- pions: nucleon and Δ-hole excitations

- short-range correlations: Migdal resummation

\[
\begin{align*}
\text{1 } \quad &= \quad + \quad + \quad + \\
\text{2 } \quad &= \quad + \quad + \quad + \\
\end{align*}
\]
Medium Modifications of Nucleons

- nucleons: $\pi^N$ and $\pi^B$, $B=\Delta(1232)$, $N^*(1440)$, $N^*(1535)$, $\Delta^*(1600)$, $\Delta^*(1620)$

- coupling constants fitted to partial decay widths $B \rightarrow \pi^N$
Medium Modifications of the $\Delta$

- Same diagram as in vacuum with dressed pion- and nucleon propagators
- Vertex corrections: same resummed Migdal loops as for the pion
- 4-fermion vertices: same Migdal parameters as for the pion

$B' = \Delta(1232), N^*(1440), N^*(1520), \Delta^*(1600), \Delta^*(1620), N^*(1700), \Delta^*(1700)$
Cold Nuclear Matter

photo absorption on the nucleon

\begin{align*}
\sigma_\gamma & [\mu b] \\
\text{model} & \\
\text{Data (p-n Average)} & 
\end{align*}

\begin{align*}
k_\gamma & [\text{GeV}] \\
0.2 & 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 & 
\end{align*}

Medium Modifications of the $\Delta(1232)$ – p.9
Cold Nuclear Matter

- photo absorption on nuclei

![Graph showing photo absorption on nuclei with different nuclear densities and various data points for different elements.]
Hot hadronic matter (RHIC)

Δ⁺⁺ Mass PDG

Δ⁺⁺ Width PDG

Δm ∼ (17 ± 7) MeV, ΔΓ ∼ (45 ± 14) MeV

Courtesy: Patricia Fachini

Medium Modifications of the Δ(1232) – p.10
Hot hadronic matter (RHIC)

Δ(1232) Spectral Function at RHIC

Δm \sim 7 \text{ MeV}, \Delta \Gamma \sim 67 \text{ MeV}
Conclusions and Outlook

- photo absorption on nuclei/$\pi N$ spectra ↔ connection of JLab and RHIC physics
- results qualitatively in line with preliminary STAR data for $\pi N$ invariant-mass spectra
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- photo absorption on nuclei/$\pi N$ spectra ↔ connection of JLab and RHIC physics
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- further developments:
  - medium effects on excited resonances
  - $\pi N$ invariant-mass spectra ↔ detailed treatment of freezeout dynamics
  - implication for vector mesons ↔ chiral framework
  - Equation of State of interacting Hadron gas/chemical freeze-out