VI Latin American Symposium on Nuclear Physics and Applications

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Search For Modification of light Vector Mesons properties in Nuclei

VI Latin American Symposium on Nuclear Physics and Its Applications
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and the CLAS Collaboration
Spontaneous Breaking of Chiral Symmetry

In Vacuum

Constituent quarks $\sim300\text{MeV}/c^2$

In Hot/Dense Matter

Current quarks $<10\text{MeV}/c^2$

Motivations

Not seen in atoms, molecules or even nuclei

\[<\bar{q}q> \neq 0\]
Hadronic properties depend on the chiral condensate $<0|q\bar{q}|0>$. $<0|q\bar{q}|0>$ changes with $\rho$ and $T$. As $<0|q\bar{q}|0> \rightarrow 0$, Restoration of chiral symmetry.

Changes in the properties of light vector mesons

QCD sum rules:


Scale invariance in effective Lagrangian:


\[
\frac{m_V^*}{m_V} = 1 - \alpha \frac{\rho_B}{\rho_0} \quad \alpha \approx 0.16 \pm 0.06
\]

\[
\frac{m_N^*}{m_N} = \frac{f_\pi^*}{f_\pi} \approx 0.8 \quad \text{At } \rho_0
\]

Are these modifications observed in RHIR?

- pionic states in Nuclei
- "\(\sigma\) meson"
- or

How to measure?
First evidence in $e^+e^-$ measurements

CERES/NA45 @ CERN?

- Large excess observed in Pb+Au below 0.7 GeV/c$^2$

- $\rho/\omega$ mass shift??

$p+Au$ understood in terms of $p+p$ superposition

- $p$-Au 450 GeV
  - $2.1 < \eta < 2.65$
  - $p_T > 50$ MeV/c
  - $\Theta_{ee} > 35$ mrad
  - $\langle dN_{ch}/d\eta \rangle = 7.0$

- CERES/NA45
  - Pb-Au 158 A GeV
  - $\sigma_{had}/\sigma_{tot} \sim 35\%$
  - $p_T > 200$ MeV/c
  - $\Theta_{ee} > 35$ mrad
  - $2.1 < \eta < 2.65$
  - $\langle N_{ch} \rangle = 250$
ρ meson properties in the medium

*Nuclear many body effects?

π, Δ coupling + ρ, ππ coupling


+ ρ, N* coupling

C+C, 1 AGeV (2004) Excess of $e^+e^-$ observed below 800 MeV/$c^2$

Romain Holzmann, GSI Darmstadt for the HADES collaboration, QM05
NA60 di-muons measurements

At least five talks at QM05, showed this figure and concluded that:

- Data consistent with broadening of the $\rho$ a la Rapp-Wambach
- Mass shift of the $\rho$ a la Brown-Rho is ruled out

Brown and Rho strongly object to these statements see: arXiv:nucl-th/0509001

**In-In SemiCentral**

all $p_T$

$\mu^+\mu^-$

$dN/dM$ per 20 MeV

$M$ (GeV)

excess data

RW (norm.)

BR (norm.)

Vac,$\rho$ (norm.)

cockt,$\rho$ (dashed)
Medium modification of vector meson properties seem to explain HI results

**HOWEVER:**

1) In A+A collisions, the results are integrated over a whole range of $\rho$ and $T$; “it is hard to get easily to the elementary process”!
2) In A+A collisions, the interesting phase of matter is produced (if at all!) in the very early stages of the reaction, generally far from equilibrium, making it hard to directly compare to the theoretical models which all assume equilibrium.
3) In A+A collisions, many channels are involved

It desirable to look for medium effects in “simpler reactions”

THIS IS POSSIBLE!!
Medium modification of vector meson properties in nuclei (at T=0 and ρ=ρ₀)

The predicted medium modifications are so large that even at ρ= normal nuclear density, they can be observed.

SO:
• Let’s produce Vector mesons in nuclei.
• Do it with probes that leave the nucleus in almost an equilibrium state γ,π,p,..
• (probe) + A --> V X

\[ e^+ e^- \]

<table>
<thead>
<tr>
<th>Vector mesons</th>
<th>ρ: M=768 MeV</th>
<th>Γ = 149 MeV</th>
<th>cτ~1.3 fm</th>
</tr>
</thead>
<tbody>
<tr>
<td>J^P=1^- ω:</td>
<td>M=782 MeV</td>
<td>Γ = 8 MeV</td>
<td>cτ~23.4 fm</td>
</tr>
<tr>
<td>φ:</td>
<td>M=1020 MeV</td>
<td>Γ = 4 MeV</td>
<td>cτ~44.4 fm</td>
</tr>
</tbody>
</table>
## Present and planned experiments
(not exhaustive list)

<table>
<thead>
<tr>
<th>Heavy ions reactions:</th>
<th>Other reactions:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RHIC</strong> p+A, d+A, A+A</td>
<td><strong>TAGX</strong> $\gamma$ +$^3$He--&gt;$\rho$+X ($\rho$-&gt;$\pi^+\pi^-$)</td>
</tr>
<tr>
<td><strong>LHC</strong> A+A</td>
<td><strong>KEK</strong> p+A--&gt;$\rho,\omega,\phi$+X ($\rho,\omega,\phi$-&gt;e$^+e^-$, $\phi$-&gt;K$^+K^-$)</td>
</tr>
<tr>
<td><strong>GSI-HADES</strong> A+A --&gt; VM+A* (VM--&gt;e$^+$e$^-$)</td>
<td><strong>SPring-8</strong> $\gamma$ + A--&gt;$\phi$+A*($\phi$--&gt; K$^+K^-$)</td>
</tr>
<tr>
<td></td>
<td><strong>Bonn-TAPS</strong> $\gamma$+A--&gt;$\omega$+X ($\omega$ --&gt; $\pi^0 \gamma$)</td>
</tr>
<tr>
<td></td>
<td><strong>JLab-g7a</strong> $\gamma$+A--&gt;($\rho,\omega,\phi$)+A* (VM--&gt;e$^+e^-$)</td>
</tr>
<tr>
<td></td>
<td><strong>-g7b</strong> same reactions</td>
</tr>
</tbody>
</table>

*Note: Running (running), 2008? (completed), more stat (completed), next PAC (completed)*
Evidence for $\rho^0$ Mass Modification in the $^3\text{He}(\gamma, \rho^0)ppn$ Reaction

TAGX Collaboration: $E_\gamma \sim 0.8-1.12\text{ GeV}$, sub-threshold $\rho_0 \rightarrow \pi^+\pi^-$

Fit with different channels: $\Delta$, $N^*$, $\Delta\Delta$, $3\pi$, ...

Claim: best fit if $m_\rho$ reduced by 160 $\pm$ 35 MeV/c$^2$

Problems: FSI, limited phase space, large effect on $^3\text{He}$???
Invariant Mass Spectrum of $e^+e^-$ ('02 Data) KEK-PS E325

Light Target (C)  Heavy Target (Cu)

"vanished $\rho$?"
Invariant Mass Spectrum of $e^+e^-$ ('02 Data) **KEK-PS E325**

φ meson

$\beta\gamma < 1.25$ ("Slow moving" φ)

Shoulder due to "modified" φ decaying in nucleus?

$\alpha \sim 0.10$
Bonn- TAPS results

\[ \gamma + A \rightarrow \omega + X \ (\omega \rightarrow \pi^0 \gamma \) , \ clean \ channel \]


Second run (to get more statistics) is planned, \( \alpha \sim 0.16 \)
Photoproduction of Vector Mesons off Nuclei
“looking for medium modifications”
\[ \gamma A \rightarrow VX \]
\[ \rightarrow e^+e^- \]

- Jlab Experiment E01-112
  Spokespersons: C. Djalali (USC), M. Kossov (ITEP),
  D. Weygand (Jlab)
- Photon beam (VDM, minimal disturbance to initial state):
  \( E_\gamma \approx 0.6 \) to 3.8 GeV (tagged gammas)
  Targets: LH\(_2\), LD\(_2\), C, Ti, Fe and Pb
- Leptonic decay:
  Almost no final state interaction!
  Low branching ratio: \( 4.49 \times 10^{-5} \)
  Needs high photon flux: \( 5 \times 10^7 \) tagged g/s
Superconducting Electron Accelerator (338 cavities), 100% duty cycle, $I_{\text{max}} = 200 \ \mu A$, $E_{\text{max}} = 6 \ \text{GeV}$, $\delta E/E = 10^{-4}$. 1500 physicists, ~30 countries, operational since end of 97
- Toroidal magnetic field
  (6 superconducting coils),
- Drift chambers, Scintillators, Cerenkovs, Electromagnetic Calorimeter.
3. $10^{-4}$ RL Radiator

Flux $\sim 5 \times 10^7 \gamma/s$

Can Tag $\gamma$ with $E_\gamma$ between 0.2 and 0.95 of $E_e$
Multi-Segment Nuclear Target

- Contains materials with different average densities.
- LD2 and seven solid foils of C, Fe, Pb, and Ti.
  Each target material 1 g/cm\(^2\) and diameter 1.2 cm

Proper spacing 2.5 cm to reduce multiple scattering
D2 target as reference, small nucleus, no modification is expected.
Typical event expected: $\gamma p \rightarrow (\rho p) \rightarrow e^+e^-p$

- For each such event, we have $\sim 10^5 \pi^+\pi^-p$ events.

- We need good $\pi/e$ discrimination

- Use CC + EC
Data Analysis

- Data taken in 2002, 4.3 M triggers, 50 nA beam.

- $e^+$ and $e^-$ identification via EC-CC coincidence.

- Additional EC-CC cuts to remove $\pi^+$, $\pi^-$ background.

- Excellent pion rejection factor of $5.4 \times 10^{-4}$ for one and $2.9 \times 10^{-7}$ for two arms.
Pion rejection efficiency with IsLepton

Sample of good pions: those that contribute to the peak in the reaction:
\[ \gamma p \rightarrow K^+\Lambda \rightarrow K^+p\pi^- \]

Plot: Invariant mass of \( p\pi^- \)

Results:
- 5861 pions
- 3 pass IsLepton EC+CC Cuts
Cuts on the vertex of the lepton candidates

- Intersection of the particle track with beam line
- Radial position in the target
- Extrapolation of the track back to target by TOF
$e^+ e^- \text{ Invariant Mass Spectra}$

No Cuts

After Vertex Cuts

Same sector
Combinatorial Background (preliminary)

Combinatorial background shape for g7 – plotted with different sector cut + IsLepton + vertex cut

In red: Scaled combinatorial background superimposed on g7 data
G7 “cocktail” BUU predictions

- The code includes various decay channels and nuclear effects, and CLAS detector simulation package (GSIM)
- Generates 7 channels: $e^+e^-$ decays of the $\rho$, $\omega$ and $\phi +$ Dalitz decays of the $\pi^0$, $\eta$, $\omega$ and $\Delta$.
- Includes conventional medium effects such as Pauli blocking, shadowing for photon induced reactions, Fermi motion of nucleons, collisional broadening (targets other than proton).
- Can add a mass shift according to the Brown-Rho formula on demand.
Simulations: proton target

Generated

After CLAS acceptance
Simulations: “cocktail” mass spectra

- **p**: Weighted invariant mass of reconstructed e+e- pairs
  - Entries: 7226
  - Mean: 0.6949
  - RMS: 0.1787

- **C**: Weighted invariant mass of reconstructed e+e- pairs
  - Entries: 27993
  - Mean: 0.7324
  - RMS: 0.1815

- **Fe**: Weighted invariant mass of reconstructed e+e- pairs
  - Entries: 27841
  - Mean: 0.7049
  - RMS: 0.1934

- **Pb**: Weighted invariant mass of reconstructed e+e- pairs
  - Entries: 28990
  - Mean: 0.6793
  - RMS: 0.1927
Empirical approach: modeling the background, using the events with $\gamma$ in time with $e^+$ and $e^-$, taking most of the beam energy.

Unlike KEK proton results, we see a strong $\rho$ signal.

All three vector mesons are clearly seen!
Masses and widths are fixed.

Mass and width of $\rho$ allowed to change.
Masses and widths are fixed. Mass and width of $\rho$ allowed to change.
Masses and widths are fixed.  

Mass and width of $\rho$ allowed to change.

Extra background contribution $\sim 0.45\text{GeV} \rightarrow$ poor fit  
Depletion of the $\omega$ much stronger than predicted by Giessen code
Fit Results with BUU shifted a la BR

Fits with BUU model including the prediction of Brown and Rho for mass and width of $\rho$.
Summary and Conclusions

- e+e- from rare leptonic decay of light vector mesons are identified.
- Clear $\omega$ and $\phi$ signals in the invariant mass spectrum.
- Depletion of $\omega$ signal with higher $A$.
- “Mixed events” for the combinatorial background needs “tuning”.
- Any final conclusions require better understanding of the low invariant mass events. Preliminary fits seem to favor a downward shift of the mass of the $\rho$-meson.

Work in progress:
- Full Monte-Carlo simulation for Bethe-Heitler, and careful determination of the combinatorial background to get final fits and quantify the mass and width modifications.

Medium modification studies continue to be a hot topic!

- Plans for follow up experiment to increase statistics.

Our group would like to thank U. Mosel and P. Muehlich for providing us with the model calculations, theoretical support and participating in several meetings and discussions during this work.