Precision Spectroscopy of Pionic Atom at RIKEN-RIBF

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In-medium change of $\langle \bar{q}q \rangle$

D. Jido et al., PLB670(2008)

**In-medium Glashow-Weinberg**

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \sim Z_{\pi}^{1/2}(\rho) \left( \frac{f^t_\pi(\rho)}{f_\pi} \right)$$

- $f_\pi$: pion decay constant
- $Z_{\pi}$: pion wave-function renormalization


**In-medium Tomozawa-Weinberg**

$$\frac{b_1}{b_1(\rho)} \sim \left( \frac{f^t_\pi(\rho)}{f_\pi} \right)^2$$

- $b_1$: isovector $\pi N$ scattering length

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \sim Z_{\pi}^{1/2}(\rho) \left( \frac{b_1}{b_1(\rho)} \right)^{1/2}$$
Deeply bound state of pionic atom

Pion-nucleus optical potential (s-wave)

\[ V_{\text{opt}} \propto b_0 (\rho_n + \rho_p) + b_1 (\rho_n - \rho_p) \]

- isoscalar
- isovector


\[ d^2 \sigma/dQdE \text{ [b/sr/MeV]} \]

\[ b_1 \]

\[ \frac{^124\text{Sn}(d,^3\text{He})}{^123\text{Sn}} \]

\[ \frac{p(d,^3\text{He})\pi^0}{(1s)\pi^-} \]

\[ @\text{GSI} \]

\[ ^{205}\text{Pb}, ^{119}\text{Sn}, ^{115}\text{Sn}, ^{123}\text{Sn} \]

average
piAF project at RIKEN-RIBF

piAF: pionic atom factory

We performed the first pilot experiment of the piAF project at RIKEN-RIBF in October 2010.
Using the \((d, {^3}\text{He})\) reaction near the recoilless condition \(T_d = 500\ \text{MeV}\), \(^{122}\text{Sn}\) target.

<table>
<thead>
<tr>
<th></th>
<th>GSI</th>
<th>RIKEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>(10^{11}/\text{s})</td>
<td>(10^{12}/\text{s})</td>
</tr>
<tr>
<td>Target</td>
<td>20 mg/cm(^2)</td>
<td>10 mg/cm(^2)</td>
</tr>
<tr>
<td>(\Delta p_d/p_d)</td>
<td>0.03%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Resolution</td>
<td>400 keV</td>
<td>200 keV</td>
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</tbody>
</table>

RIKEN RIBF
Dispersion matching

\[
\begin{pmatrix}
x \\
\theta \\
\delta \\
\end{pmatrix} =
\begin{pmatrix}
s_{11} & s_{12} & s_{16} \\
s_{21} & s_{22} & s_{26} \\
0 & 0 & 1 \\
\end{pmatrix}
\begin{pmatrix}
b_{11} & b_{12} & b_{16} \\
b_{21} & b_{22} & b_{26} \\
0 & 0 & 1 \\
\end{pmatrix}
\begin{pmatrix}
x_0 \\
\theta_0 \\
\delta_0 \\
\end{pmatrix}
\]

Beam position at focal plane

\[
x = (b_{11}s_{11} + b_{21}s_{12})x_0 \\
+ (b_{12}s_{11} + b_{22}s_{12})\theta_0 \\
+ (b_{16}s_{11} + b_{26}s_{12} + s_{16})\delta_0
\]

Dispersion matching condition

\[
b_{16}s_{11} + b_{26}s_{12} + s_{16} = 0
\]
Matching condition with the target

\[ b_{16}s_{11} + b_{26}s_{12} + Cs_{16} = 0 \]

\( C \) : kinetic factor of the \((d,^3\text{He})\) reaction

- \( b_{16} = 46 \text{ [mm/\%]} \)
- \( b_{26} = 0.0 \text{ [mm/mrad]} \)
- \( s_{11} = -1.8 \)
- \( s_{12} = 0.0 \text{ [mm/mrad]} \)
- \( s_{16} = 64 \text{ [mm/\%]} \)

**b_{16} measurement**

- \( b_{16} = 43.8 \text{ [mm/\%]} \)

**s_{16} measurement**

- \( s_{16} = 60.9 \text{ [mm/\%]} \)
Experimental setup

RIKEN RIBF

SRC

3He, p, d

d

Target

F5 focal plane
MWDC x 2
Segmented scinti. x 1

F7 focal plane
Scinti. x 1

Particle identification

\[
\begin{align*}
\text{ADC [ch]} & \quad \text{TOF [ns]} \\
& \quad \text{3He} \\
& \quad p \\
& \quad d
\end{align*}
\]
New data of $^{121}$Sn pionic atom


$^{122}$Sn($d,^{3}\text{He})$

Preliminary before acceptance correction
New data of $^{121}$Sn pionic atom

-7 < A [mrad] < 7  A: horizontal beam angle
-9 < B [mrad] < 9  B: vertical beam angle

Obtained histogram with a selection of the forward reaction is similar shape to the previous GSI experiment.
Beam position vs beam angle

Counts

-10 < A [mrad] < 10

B [mrad]

A: horizontal beam angle
B: vertical beam angle

1s state is dominant for the forward emission angle.
Resolution of the full target is comparable with that of the strip target. However, there is room for improvement to achieve 200 keV resolution.
1. We performed the precision spectroscopy experiment of the pionic atom at RIKEN-RIBF in October 2010.

2. The dispersion matching was realized. However, there is room for improvement.

3. We observed the deeply bound $1s$ state (and others) of the $^{121}$Sn pionic atom.

4. Future plans
   - To deduce the binding energy and the width of the deeply bound state.
   - Improvement of the dispersion matching for the next experiment.
piAF collaboration (October 2010)