Phenomenology of spin 3/2 baryons with pentaquarks

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Introduction: Flavor SU(3) symmetry

Existence of $\Theta^+$ Flavor SU(3) symmetry

- Existence of flavor partners of $\Theta^+$

Assuming the flavor multiplet that $\Theta^+$ belongs to, we examine its properties by symmetry relation, in connection with known baryon resonances.

- to determine the $J^P$ of $\Theta^+$

Phenomenological but model independent analysis up to $O(m_s)$
Pure antidecuplet case

Simplest assignment for $\Theta^+$

Test the masses and widths of partners via flavor SU(3) symmetry relations
Pure antidecuplet case

Mass and decay width [MeV]

\[ M(\bar{10}; Y) = M_{\bar{10}} - aY \]

\[ g_{\Theta KN} = \sqrt{6} g_{N^* \pi N} \]

<table>
<thead>
<tr>
<th>J^P</th>
<th>M_\Theta</th>
<th>M_N</th>
<th>M_\Sigma</th>
<th>M_\Xi</th>
<th>\Gamma_\Theta</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2^-</td>
<td>1540 (\Theta(1540))</td>
<td>1647 (N(1650))</td>
<td>1753 (\Sigma(1750))</td>
<td>1860 (\Xi(1860))</td>
<td>156.1</td>
</tr>
<tr>
<td>1/2^+</td>
<td>1540 (\Theta(1540))</td>
<td>1710 (N(1710))</td>
<td>1880 (\Sigma(1880))</td>
<td>2050 (\Xi(2030))</td>
<td>7.2</td>
</tr>
<tr>
<td>3/2^+</td>
<td>1540 (\Theta(1540))</td>
<td>1720 (N(1720))</td>
<td>1900</td>
<td>2080</td>
<td>10.6</td>
</tr>
<tr>
<td>3/2^-</td>
<td>1540 (\Theta(1540))</td>
<td>1700 (N(1700))</td>
<td>1860</td>
<td>2020 (\Xi(2030))</td>
<td>1.3</td>
</tr>
</tbody>
</table>

are not reproduced simultaneously.
Octet-antidecuplet mixing

Second simplest assignment for $\Theta^+$

Mixing is induced by the SU(3) breaking in mass term.
Mass formulae

\[ M_\Theta = M_{10} - 2a \]
\[ M_{\Xi_{10}} = M_{10} + a \]
\[ M_\Lambda = M_8 \]
\[ M_{\Xi_8} = M_8 + b + \frac{1}{2} c \]
\[ M_{N_1} = \left( M_8 - b + \frac{1}{2} c \right) \cos^2 \theta_N + (M_{10} - a) \sin^2 \theta_N - \delta \sin 2\theta_N \]
\[ M_{N_2} = \left( M_8 - b + \frac{1}{2} c \right) \sin^2 \theta_N + (M_{10} - a) \cos^2 \theta_N + \delta \sin 2\theta_N \]
\[ M_{\Sigma_1} = (M_8 + 2c) \cos^2 \theta_\Sigma + M_{10} \sin^2 \theta_\Sigma - \delta \sin 2\theta_\Sigma \]
\[ M_{\Sigma_2} = (M_8 + 2c) \sin^2 \theta_\Sigma + M_{10} \cos^2 \theta_\Sigma + \delta \sin 2\theta_\Sigma \]

8 masses v.s. 6 parameters

\( J^P = 1/2^- \): too wide width
\( J^P = 3/2^+ \): states are not well established
Mass spectra

1/2^+

$\Sigma_8$, $\Xi_8$, $\Sigma_{10}$, $\Xi_{10}$, $\Sigma(1880)$, $\Xi(1860)$

3/2^-

$\Xi_8$, $\Xi_{10}$, $\Sigma_2$, $\Xi(1820)$, $\Xi(1860)$

Mass spectrum [MeV]

8 10 Theory Exp.
### Decay width of $\Theta$

#### Relation between coupling constants

$$g_{\Theta} = \sqrt{6}(g_{N_2} \cos \theta_N - g_{N_1} \sin \theta_N)$$

#### C.G. Coeff.  N* decay from masses

<table>
<thead>
<tr>
<th>$J^P$</th>
<th>$\theta_N$ [deg]</th>
<th>$\Gamma_{\Theta}$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/2^+$</td>
<td>29</td>
<td>29.1</td>
</tr>
<tr>
<td>$3/2^-$</td>
<td>33</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Two-meson coupling

Then, what about two-meson coupling?

SU(3) relation enable us to calculate

the cross section of

from the decay of nucleons into two pions.
Two-meson coupling

Contact interaction:

Talk by Llanes-Estrada
### Two-meson coupling

#### Branching fraction [%]

<table>
<thead>
<tr>
<th>$J^P$</th>
<th>state</th>
<th>$\pi N$</th>
<th>$\pi\pi N(s)$</th>
<th>$\pi\pi N(v)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/2^+$</td>
<td>N(1440)</td>
<td>65</td>
<td>7.5</td>
<td>&lt;8</td>
</tr>
<tr>
<td></td>
<td>N(1710)</td>
<td>15</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>$3/2^-$</td>
<td>N(1520)</td>
<td>55</td>
<td>25</td>
<td>&lt;85-95</td>
</tr>
<tr>
<td></td>
<td>N(1700)</td>
<td>10</td>
<td>&lt;35</td>
<td></td>
</tr>
</tbody>
</table>

**Still large uncertainty**
Constraints on the coupling

Self-energy: not too large, but not too small

$\pi^- p \rightarrow K^- \Theta^+$ at KEK: upper limit is $\sim 4.1 \, \mu b$

$\sim 100 \, \text{MeV}$

It is necessary to use the interference effect among two terms, $s$ and $v$. 

$< 4.1 \, \mu b$
\[ \pi^- p \rightarrow K^- \Theta^+ \]

\[ K^+ p \rightarrow \pi^+ \Theta^+ \]

\[ \sigma(K^+) \]

\[ \sigma(\pi^-) \sim 50 \]

\[ \sigma(K^+ \rightarrow \pi^-) \]

\[ \sigma(\pi^- \rightarrow \pi^+) \sim 3 \]

\[ \Theta \] production

1/2^+

3/2^−

large interference

small interference

\[ \sigma(K^+) \]

\[ \sigma(\pi^-) \]

\[ \sigma(K^+) \]

\[ \sigma(\pi^-) \]
Summary 1 : mixing scheme

We examine 8–10 mixing scheme for the exotic and non-exotic baryon resonances.

Masses of $\Theta(1540)$ and $\Xi(1860)$ are well fitted in the 8–10 mixing scheme with $J^P = 1/2^+$ or $3/2^-$ baryons.

The width of $\Theta$ is very narrow for the $J^P = 3/2^-$ case.

For both cases, the mixing angle is close to the ideal angle.

Summary 2: Two-meson coupling and Θ production

Based on the mixing scheme, we evaluate the two-meson coupling of Θ, and calculate the reaction process for Θ production.

There is an interference effect between two amplitudes, which is prominent for $1/2^+$ case and rather moderate for $3/2^-$ case.

<table>
<thead>
<tr>
<th>$J^P$</th>
<th>$g^s$</th>
<th>$g^v$</th>
<th>$\sigma_{\pi^-}$</th>
<th>$\sigma_{K^+}$</th>
<th>ReΣ(\Theta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/2^+$</td>
<td>1.59</td>
<td>-0.27</td>
<td>4.1 µb</td>
<td>&lt;1928 µb</td>
<td>-78 MeV</td>
</tr>
<tr>
<td>$3/2^-$</td>
<td>0.104</td>
<td>0.209</td>
<td>4.1 µb</td>
<td>&lt;113 µb</td>
<td>-23 MeV</td>
</tr>
</tbody>
</table>