The $K\Sigma$ production in pion- and photo-induced reactions

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Introduction

Conventional quark model

- missing resonance
  1. More states are predicted in quark models than seen in the $\pi N$ scattering
Introduction

- The $K\Sigma$ production in photo-induced reactions: High precision data from CBELSA, LEPS, CLAS, Graal and SAPHIR groups.

1. resonances with isospin $I = 3/2$

2. most of the models are based on the old database before 2000.

3. the current inconclusive status of the old isobar models:
   - new resonances?

4. the coupled-channel analysis of the $K\Sigma$ photoproduction is scarce.
   - The Juelich-George-Washington group
   - The Excited Baryon Analysis Center (EBAC) at JLab

$\implies$ A Coupled-Channel Analysis with $J \leq 5/2$ and $\sqrt{s} < 2.0$ GeV.
Coupled-Channel model

\[ T_{fi} = V_{fi} + V_{fa} G_{ab} T_{bi} \implies T_{fi} = K_{fi} + iK_{fa} \text{Im}G_{ab} T_{bi} \]

K-matrix approximation

\[ G_{ab} = \text{Re}G_{ab} + i\text{Im}G_{ab} \implies T_{fi}^{J\pm,l} = \frac{K_{fi}^{J\pm,l}}{1 - iK_{fi}^{J\pm,l}} \]

Unitarity holds easily with technical simplicity and flexibility but at the cost of analyticity.

final states: \( \gamma N, \pi N, \pi\pi N, \eta N, \omega N, K\Lambda, K\Sigma \)

Feuster & Penner & Shklyar & Lenske & Mosel:
PRC58,457;59,460(1999);PRC66,055211;055212(2002);
EPJA21,445;PRC71,055206;72,015210;PLB650,172(2007)
Coupled-Channel model

\[ K_{fi} = V_{fi} + V_{fa} \text{Re} G_{ab} K_{bi} : s, u, t \text{-channel} \]

K-matrix approximation

- \[ G_{ab} = \text{Re} G_{ab} + i \text{Im} G_{ab} \Rightarrow T_{fi}^{J\pm, I} = \frac{K_{fi}^{J\pm, I}}{1 - iK_{fi}^{-J\pm, I}} \]

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Coupled-Channel model

- 11 $N^*$ resonances with $I = 1/2$
- 9 $\Delta^*$ resonances with $I = 3/2$

Elastic $\pi N$ partial waves:

$\gamma N \rightarrow \pi N$ multipoles: GWU

<table>
<thead>
<tr>
<th>$\Delta^*$</th>
<th>$A_{1/2}$</th>
<th>$A_{3/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{31}(1620)$</td>
<td>-58</td>
<td>—</td>
</tr>
<tr>
<td>$P_{31}(1750)$</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>$P_{33}(1232)$</td>
<td>-128</td>
<td>-253</td>
</tr>
<tr>
<td>$P_{33}(1600)$</td>
<td>-10</td>
<td>-17</td>
</tr>
<tr>
<td>$P_{33}(1920)$</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>$D_{33}(1700)$</td>
<td>97</td>
<td>147</td>
</tr>
<tr>
<td>$D_{35}(1930)$</td>
<td>-66</td>
<td>1</td>
</tr>
<tr>
<td>$F_{35}(1905)$</td>
<td>54</td>
<td>-127</td>
</tr>
<tr>
<td>$F_{35}(2000)$</td>
<td>18</td>
<td>-23</td>
</tr>
</tbody>
</table>
the $\pi N \rightarrow 2\pi N$ partial cross sections (SAID) and $\pi N$ inelasticity
(Manley et al.) $\Rightarrow \zeta[1(0^+)] = 2\pi$
Baryon spectrum

The diagram shows the baryon spectrum with mass values ranging from 1100 MeV to 2100 MeV. The spectrum includes states labeled with angular momentum labels such as $S_{11}$, $P_{11}$, $P_{31}$, $P_{13}$, $P_{33}$, $D_{13}$, $D_{33}$, $D_{15}$, $D_{35}$, $F_{15}$, and $F_{35}$. The mass values are marked at specific points on the horizontal axis, with notable states at 1232 MeV, 1535 MeV, 1600 MeV, 1700 MeV, and 1900 MeV. The spectrum is categorized into substates with angular momentum $L_{IJ}$, indicating the classification of baryon states based on their quantum numbers.
The $K\Sigma$ production in pion-induced reactions

differential and polarization observables? fairly good!

1 $\pi^+ p \rightarrow K^+ \Sigma^+$: $I = 3/2$
   - $P_{31}$ dominates at threshold.
   - $D_{35}$ and $P_{33}$: high energies.
   - $S_{31}$: close-to-threshold.
   - $F_{35}$: negligible.

2 $\pi^- p \rightarrow K^+ \Sigma^-$ and $K^0 \Sigma^0$
   - $S_{11}$ dominates at threshold.
   - $P_{31}$, $P_{33}$, $D_{35}$, $D_{15}$: high energies.

3 $S_{11}(1650), P_{11}(1440), D_{15}(1675)$
   $P_{33}(1600), P_{31}(1750), D_{33}(1700)$
   $D_{35}(1930)$
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17 May, 2013
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- $\pi^- p \to K^0\Sigma^0$: differential cross section
- Full model vs the calculation with the $S_{11}(1650)$ turning off
The $K\Sigma$ production in pion-induced reactions

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However.... $\pi N$ data is not enough for the model calculation.

i.e. $\pi^+ p \rightarrow K^+ \Sigma^+$:

1. Giessen model: $P_{31}$ dominates at threshold, $D_{35}$ and $P_{33}$ are important at high energies.

2. Juelich model: $S_{31}$ dominates, $F_{37}$ is seemed at high energies.

3. Bonn-Gatchina model: $P_{33}$ is the most essential, and high partial waves are important at high energies.

Secondary $\pi$ beams are expected in GSI-HADES and J-PARC.

- Conventional $\pi N$ experiment revived?

- Plenty of photoproduction data should be used.
The $K\Sigma$ production in photo-induced reactions

1. $\gamma p \rightarrow K^0\Sigma^+$: 
   - SAPHIR, CBELSA, CLAS
   - $S_{I1}$, $P_{I1}$ and $P_{I3}$
   - Small total cross section.
   - Why?
   - the destructive interference of background and resonance contributions!

2. $\gamma p \rightarrow K^+\Sigma^0$: CLAS, SAPHIR
   - dominated by the $S_{I1}$-wave

3. $P_{31}(1750), D_{33}(1700), D_{35}(1930), F_{35}(1905)$

4. $S_{11}(1650), D_{13}(1520), D_{15}(1675), F_{15}(1680)$
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The $K\Sigma$ production in photo-induced reactions

- $\gamma p \rightarrow K^+\Sigma^0$: differential cross sections, CLAS PRC82(2010)
- Full model compared to background terms
The $K\Sigma$ production in photo-induced reactions

- $\gamma p \to K^+\Sigma^0$: CLAS PRC75(2007), 82(2010) polarization observables
- $C_z$: determined by the Born term with additional small structures from resonances
- $C_x$: $D_{33}(1700)$ important in dcs, however...
- $F_{35}(1905)$ and $F_{15}(1680)$ are seen
The $K\Sigma$ production in photo-induced reactions

- $\gamma p \rightarrow K^+\Sigma^0$: beam asymmetry
- Full model vs the calculation with the $D_{35}(1930)$ turning off
The $K\Sigma$ production in photo-induced reactions

- $\gamma p \rightarrow K^0\Sigma^+$:
  - CBELSA EPJA35(2008)
  - less accurately reproduced, becoming worse above 1.9 GeV

- problem in the $P_{11}$-wave at high energies?

- recoil polarization:
  - data with large error bars.
The $K\Sigma$ production in photo-induced reactions

<table>
<thead>
<tr>
<th></th>
<th>$g_{NK\Sigma}$</th>
<th>$g_{NK_0^*\Sigma}$</th>
<th>$g_{NK^*\Sigma}$</th>
<th>$\kappa_{NK^*\Sigma}$</th>
<th>$g_{NK_1\Sigma}$</th>
<th>$\kappa_{NK_1\Sigma}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>new</td>
<td>-5.41</td>
<td>-32.94</td>
<td>0.83</td>
<td>-1.71</td>
<td>3.67</td>
<td>-2.58</td>
</tr>
<tr>
<td>old</td>
<td>2.48</td>
<td>-26.15</td>
<td>4.33</td>
<td>-0.86</td>
<td>22.80</td>
<td>2.40</td>
</tr>
</tbody>
</table>

**Table:** Born couplings in the model.

- **$t$-channel $K_1$ and $K^*_0$ meson exchange:** small
- **$K\Lambda$ production, PRC72,015210(2005):**
  
  \[ g_{NK\Lambda} = -6.04 \text{ (CLAS)} \text{ or } -4.70 \text{ (SAPHIR)} \]

  \[ \Rightarrow \text{SU(3) symmetry: the relative sign of } NK\Sigma \text{ and } NK\Lambda \text{ is negative} \]
- **$D_{13}(1520)$, $D_{15}(1675)$, $D_{35}(1930)$ and $F_{15}(1680)$ states,** have large couplings to the $K\Sigma$ channel.
The $K\Sigma$ production in nucleon-nucleon reactions

- $pp \rightarrow nK^+\Sigma^+$: total cross section
- Resonance model: J. J. Xie, C. Wilkin, X. CAO, B. S. Zou
The $K\Sigma$ production in nucleon-nucleon reactions

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The $K\Sigma$ production is a good probe to explore the isospin $I = 3/2$ resonances

The $K\Sigma$ production mechanism is much more complicated than that concluded from the previous Giessen model studies after taking into account the new data.

Overall, our results agree well with the data. However, there are puzzling exceptions, namely the double polarization spin transfer coefficients in $\gamma p \rightarrow K^+\Sigma^0$ and the differential cross sections of $\gamma p \rightarrow K^0\Sigma^+$ which are awaiting further investigation.....

improvement: 'generic' $2\pi N$ channel $\Rightarrow \rho N, \sigma N$ and $\pi\Delta$ channels

Thank you!!!