Production of $\Xi^-$ hypernuclei via the $(K^-, K^+)$ reaction within a field theoretic approach

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• Introduction
• A brief review and comparison of production reactions
• Brief sketch of the theoretical model
• Results, cross sections
• Summary and Outlook
$S = -2$, $\Xi$ Hypernuclei at J-PARC, JAPAN by ($K^-$, $K^+$) reaction, No definite evidence. So far only $\Lambda\Lambda$ hypernuclei

$S = -1$
So far: $\Lambda$ and $\Sigma$, at BNL, KEK, FINUDA
For a detailed understanding of the quark aspect of the baryon-baryon forces in the SU(3) space, information on the YY channel is essential.

- Are there $S=-2$ deeply bound $\bar{K}$ states??

- **Search for** $H$ particle

Six-quark system $uuddss$

Conjectured composition of a neutron star

Mechanism of the production of $\Xi$ hyperon and $\Xi$ hypernuclei in $(K^-,K^+)$ reaction on proton and nuclei

S-channel and u-channel diagrams for elementary reaction

Cascade hypernuclear production in s-channel

$\Lambda(1116)$, $\Sigma(1189)$, $\Lambda(1405)$, $\Lambda(1670)$, $\Lambda(1180)$, $\Lambda(1890)$, $\Lambda(1520)$, $\Sigma(1750)$, $\Sigma(1385)$, $\Sigma(1670)$
Covariant Description of $A (K^-, K^+) \Xi B$ reaction,
Effective Lagrangian model

- Effective Lagrangians at Meson-baryon-Resonance vertices

Coupling constants, form-factors (from the description of elementary reaction)

- Propagators for resonances (spin-1/2, spin-3/2)
- Bound state nucleon (hole) and hyperon (particle) spinors
- Initial and final state interactions (distorted waves).
- Medium effects of Resonances

All calculations in momentum space, so nonlocalities are included.
Effective Lagrangian model for the $p \ (K^-, K^+, 0) \ \Xi^- \ (\Xi^0)$

$\Lambda(1116), \Lambda(1180), \Lambda(1405), \Lambda(1520), \Lambda(1670), \Lambda(1890)$

$\Sigma(1189), \Sigma(1385), \Sigma(1670), \Sigma(1750)$

The information about the coupling constants is very scanty

From SU(3) model, old experimental determinations

Elementary reactions for $\Xi^-$ production, Role of resonances

Bound state spinors

A mean field approach

Momentum space Dirac Eq.

\[ \not{p} \psi(p) = m_N \psi(p) + F(p), \]

\[ F(p) = \delta(p_0 - E) \left[ \int d^3p' V_s(-p') \psi(p + p') - \gamma_0 \int d^3p' V_s^0(-p') \psi(p + p') \right]. \]

\[ \psi(p) = \delta(p_0 - E) \left( \begin{array}{c} f(k) Y_{\ell_1/2j}^{m_j}(\hat{p}) \\ -ig(k) Y_{\ell'/1/2j}^{m_j}(\hat{p}) \end{array} \right), \]

\[ F(p) = \delta(p_0 - E) \left( \begin{array}{c} \zeta(k) Y_{\ell_1/2j}^{m_j}(\hat{p}) \\ -i\zeta'(k) Y_{\ell'/1/2j}^{m_j}(\hat{p}) \end{array} \right), \]

Cascade bound states

**Phenomenological Model**

Dirac equation with scalar and vector fields having WS radial shapes depths are searched to reproduce the BE of a given state.

No cascade bound states are known experimentally, So we adopt the QMC model predictions of BEs.

Review, PPNP 58, 1 (2007)

Light \((u,d)\) quarks interact self-consistently with mean \(\sigma\) and \(\omega\) fields

Lagrangian Densities, Equations of Motions, Solve self consistently
Cascade bound states

Phenomenological QMC model

(a) $1s_{1/2}^{\nu}^{12}\text{Be}$, BE 3.038 MeV

(b) $1s_{1/2}^{\nu}^{12}\text{Be}$

(c) $1s_{1/2}^{\nu}^{28}\text{Mg}$, BE 8.982 MeV

(d) $1s_{1/2}^{\nu}^{28}\text{Mg}$
Cross section for $\Xi^-$ hypernuclear production

Single particle-single-hole ($\Xi p^{-1}$) structure

Ξ-hypernuclear production cross sections: Comparison of New and old calculations


Difference between Old and our New results: further Discussion
H dibaryon production by \((K^-,K^+)\) reaction

Aerts and Dover, Phys. Rev. D28 (1983) 450

R. Shyam et al. to be published

Factorization approximation

Same vertex constants and form factors

MORE CHECK ON THE INPUT Ingredients of our model

\[ ^{12}\text{C}(K^-,K^+)H^{10}\text{Be} \]

\[ p_{K^-} = 1.67 \text{ GeV/c} \]

\[ \theta_{K^+} = 0^\circ \]

\[ ^{12}\text{C}(K^-,K^+\Lambda\Lambda X) \]
Distortion Effects in the incoming and outgoing Channels

Calculations are done with plane waves for the scattering wave functions ($K^-$ and $K^+$).

Distortion effects are partially included by introducing overall reduction factors. \( 2.8 \) for $^{12}$C and \( 5 \) for $^{28}$Si (Ikeda, PTP 91 (1994) 747)

Same procedure as in Dover and Gal, Ann. Phys. 146 (1983) 256

Difference in the peak position and magnitudes of the peak Cross sections are not due to the distortion effects due different treatments of the reaction dynamics
H Dibaryon production by $(K^-, K^+)$ reaction

Aerts and Dover, Phys. Rev. D28 (1983) 450

FURTHER CHECK ON THE INPUT

Same vertex constants and form factors

R. Shyam et al. to be published
SUMMARY AND OUTLOOK

A new description of the Ξ hypernuclear production via (K−, K+) reaction based on the mechanism of hyperon resonance excitation and decay. New results differ significantly from the older one.

A covariant description of the reaction is required.

Bound state spinors from the QMC model (quark-based) and phenomenological model

We used the same vertex parameters to study the production of the H dibaryon via (K−,K+) reaction on 12C target.

New Measurements of some key quantities to resolve the differences between the old and present calculations. J-PARC facility should be ideal for this purpose. (E.g., elementary cross section.)

Collaborators: O. Scholten, K. Tshushima, A.W. Thomas
Low momentum transfer

Momentum transfer $> p_F$

Large Momentum transfers

$^{12}\text{C}$

$^{3}\text{He}$

(K$^-$, K$^+$)

Momentum transfer $> p_F$

(K$^+$, K$^+$)

$^{12}\text{C}$

Beam Energy (GeV)

$p_{lab}$ (GeV/c)
<table>
<thead>
<tr>
<th>Intermediate state (R)</th>
<th>LIJ</th>
<th>M (GeV)</th>
<th>Width (GeV)</th>
<th>$g_{KR\Sigma}$</th>
<th>$g_{KR\Xi}$</th>
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</thead>
<tbody>
<tr>
<td>$\Lambda$</td>
<td></td>
<td>1.116</td>
<td>0.0</td>
<td>-16.750</td>
<td>10.132</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td></td>
<td>1.189</td>
<td>0.0</td>
<td>5.580</td>
<td>-13.500</td>
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<tr>
<td>$\Lambda(1405)$</td>
<td>S01</td>
<td>1.406</td>
<td>0.050</td>
<td>1.585</td>
<td>-0.956</td>
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<tr>
<td>$\Lambda(1670)$</td>
<td>S01</td>
<td>1.670</td>
<td>0.035</td>
<td>0.300</td>
<td>-0.182</td>
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<tr>
<td>$\Lambda(1810)$</td>
<td>P01</td>
<td>1.180</td>
<td>0.150</td>
<td>2.800</td>
<td>0.800</td>
</tr>
<tr>
<td>$\Lambda(1890)$</td>
<td>P03</td>
<td>1.890</td>
<td>0.100</td>
<td>0.800</td>
<td>0.800</td>
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<tr>
<td>$\Lambda(1520)$</td>
<td>D03</td>
<td>1.520</td>
<td>0.016</td>
<td>-27.46</td>
<td>-16.610</td>
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<tr>
<td>$\Sigma(1750)$</td>
<td>S11</td>
<td>1.750</td>
<td>0.090</td>
<td>0.500</td>
<td>0.500</td>
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<tr>
<td>$\Sigma(1385)$</td>
<td>P13</td>
<td>1.383</td>
<td>0.036</td>
<td>-6.22</td>
<td>-0.220</td>
</tr>
<tr>
<td>$\Sigma(1670)$</td>
<td>D13</td>
<td>1.670</td>
<td>0.060</td>
<td>2.80</td>
<td>0.800</td>
</tr>
</tbody>
</table>
The QMC model

P. Guichon, PLB 200, 235 (1988)

Light (u,d) quarks interact self-consistently with mean $\sigma$ and $\omega$ fields

$\langle \sigma \rangle$

$\langle \omega \rangle$

Nuclear Binding !!

Self-consistent !

$M^*_N \approx M_N - g_\sigma \sigma + (d/2) (g_\sigma \sigma)^2$

For a review, PPNP 58, 1 (2007)

Applied quark model !)