DN and $\bar{K}N$ interactions with the Jülich meson-exchange model

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5. Summary
Λ(1405) $S_{01}$ resonance $\Leftrightarrow$ $\bar{K}N$ threshold $\approx 1435$ MeV

$\chi$PT + unitarization:

- dynamically generated $\Lambda(1405)$
- two-pole structure of the $\Lambda(1405)$


... 

What about other approaches?

- meson exchange $\rightarrow$ Jülich $\bar{K}N$ model
The Jülich $KN$ model

$$\bar{K}N - \pi\Lambda - \pi\Sigma \text{ coupled channel model}$$

$$T = V + TG_0V$$

$$V = \begin{pmatrix}
V_{\bar{K}N} & V_{\bar{K}N\leftarrow\pi\Lambda} & V_{\bar{K}N\leftarrow\pi\Sigma} \\
V_{\pi\Lambda\leftarrow\bar{K}N} & V_{\pi\Lambda} & V_{\pi\Lambda\leftarrow\pi\Sigma} \\
V_{\pi\Sigma\leftarrow\bar{K}N} & V_{\pi\Sigma\leftarrow\pi\Lambda} & V_{\pi\Sigma}
\end{pmatrix};
G_0 = \begin{pmatrix}
G_{0,\bar{K}N} & 0 & 0 \\
0 & G_{0,\pi\Lambda} & 0 \\
0 & 0 & G_{0,\pi\Sigma}
\end{pmatrix}$$

$$W_{\bar{K}\Lambda N} = \Gamma_{\bar{K}\Lambda N} g_{K\Lambda N} F_{K\Lambda N}(\bar{q}_K^2)$$

$$F_{K\Lambda N}(\bar{q}_K^2) = \frac{\Lambda_{K\Lambda N}^2 - m_N^2}{\Lambda_{K\Lambda N}^2 + \bar{q}_K^2}$$

$g_{K\Lambda N}, \Lambda_{K\Lambda N}$ ... fixed from SU(3) and $YN$; $g_{\rho NN}, \Lambda_{\rho NN},$ ... fixed from $NN$

$g_{\rho K\bar{K}},$ ... fixed from decay width $\rho \rightarrow \pi\pi + \text{SU(3)}$

$g_{\sigma K\bar{K}}, \Lambda_{\sigma K\bar{K}},$ ... free parameters – and there is a $\sigma_{rep}!$
$\bar{K}N$ and $K\bar{N}$ are connected via $G$-parity

($G$-parity: Charge conjugation plus $180^\circ$ rotation around the $y$ axis in isospin space)

$\Rightarrow$

\[
V_{\bar{K}N}(\omega) = -V_{K\bar{N}}(\omega) - \text{odd } G \text{ - parity}
\]

\[
V_{\bar{K}N}(\sigma, \rho) = +V_{K\bar{N}}(\sigma, \rho) - \text{even } G \text{ - parity}
\]

R. Büttgen et al., ZPC 46 (1990) S167:

- $KN$ data (S-waves) require a stronger repulsion than generated by $\omega$ exchange with a $SU(3)\omega NN (\omega KK)$ coupling constant
- $KN$ data (S-waves) require a shorter ranged repulsion than generated by $\omega$ exchange
- $KN$ and $\bar{K}N$ data cannot be described simultaneously with the same $\omega$ exchange (fixed by $G$-parity)

$\Rightarrow$ A phenomenological short-ranged repulsion was introduced ($m^{\omega}_{\text{rep}} \approx 1.2$ GeV) with different coupling constants for $KN$ and $\bar{K}N$
How many channels (and which ones) should be taken into account?

**Chiral unitary approaches:**
all channels involving members of the SU(3) pseudo-scalar octet and the SU(3) $J^P = (1/2)^+$ baryon octet: 
($\pi\Lambda$, $\pi\Sigma$, $\bar{K}N$, $\eta\Lambda$, $\eta\Sigma$, $K\Xi$)

**Jülich meson-exchange model:**
all channels that are already open at the $\bar{K}N$ threshold: 
$\rightarrow \pi\Lambda$, $\pi\Sigma$

channels that contribute significantly to the $KN$ inelasticities: 
$\rightarrow K\Delta$, $K^*N$, $K^*\Delta$

Missing in both approaches:
$\pi\pi\Lambda \approx \sigma\Lambda$, $\rho\Lambda$
Johann Haidenbauer  

**Kinematics**

\[s^{(1/2)} \text{ [MeV]}\]

- \(\pi\Lambda\)
- \(\pi\Sigma\)
- \(\pi\pi\Lambda\)
- \(\bar{K}N\)
- \(\bar{K}N\pi\)
- \(\eta\Lambda\)
- \(\eta\Sigma\)
- \(\bar{K}\Xi\)
- \(\bar{K}\Delta\)
- \(\bar{K}^*N\)
Contributions to $KN$ in the Jülich model

\[ \bar{K} \rightarrow N \]
\[ K^* \rightarrow N \]
\[ \pi \rightarrow \Lambda, \Sigma \]
\[ \rho, \omega \rightarrow \bar{K}N \]
\[ \sigma, \sigma_{\text{rep}} \rightarrow \bar{K}N \]
\[ \Lambda, \Sigma \rightarrow K N \]

\[ \pi, \rho \rightarrow \bar{K}N \]
\[ \pi, \rho \rightarrow K^*N \]
\[ \rho \rightarrow \Sigma \left[ \Lambda \right] \]

\[ \pi \rightarrow \Sigma \]
\[ \pi \rightarrow \Lambda \]
\[ \rho \rightarrow \bar{K}N \]
\[ \rho \rightarrow \bar{K}N \]

\[ \bar{K} \rightarrow N \]
\[ K^* \rightarrow N \]
\[ \pi \rightarrow \Lambda, \Sigma \]
\[ \rho, \omega \rightarrow \bar{K}N \]
\[ \sigma, \sigma_{\text{rep}} \rightarrow \bar{K}N \]
\[ \Lambda, \Sigma \rightarrow K N \]

\[ \pi \rightarrow \Lambda \]
\[ \pi \rightarrow \Sigma \]
later developments:

• 1995: $\sigma$ is replaced by correlated $\pi\pi \rightarrow K\bar{K}$ exchange
A new $KN$ model is presented
(M. Hoffmann et al., NPA 593 (1995) 341)

• 2002: a modified Jülich $KN$ model is published
The “$\sigma_{rep}$” of the original Jülich model
can be explained (replaced) by genuine quark-gluon exchange
processes ($+ a_0(980)$ exchange)
A comparable if not better description of the $KN$ phase shifts and
data can be achieved.

• 2007-11: Extension of the Jülich $KN$ model to $DN$ and $\bar{D}N$ under
the assumption of $SU(4)$ symmetry

However, no activity with regard to the $K\bar{N}$ interaction since 1990!
Fig. 5. Total cross sections in six different particle channels as predicted by model II which, in addition to model I, contains a pole graph motivated by \( A(1670) \).

\( g_p = -12.5 \) suggested from interpreting the short-ranged repulsion in the \( K\bar{N} \) system as consisting entirely of contributions with negative G-parity.

Finally, fig. 6 demonstrates that model II predicts essentially the same mass spectrum for \( A(1405) \).

Thus the conclusion obtained before about the nature of the \( A(1405) \), as well as our arguments concerning the short-ranged part of the interaction, remain unchanged.

\[ K^- p \rightarrow K^- p \]

\[ K^- p \rightarrow \bar{K}^0 n \]

\[ K^- p \rightarrow \pi^0 \Lambda \]

\[ K^- p \rightarrow \pi^0 \Sigma^0 \]

\[ K^- p \rightarrow \pi^- \Sigma^+ \]

\[ K^- p \rightarrow \pi^+ \Sigma^- \]
M. Hoffmann et al., NPA 593 (1995) 341
Fig. 11. The same as in Fig. 7 for K+p and K+n polarizations. Experimental data are taken from Ref. [20] (K+p) and Ref. [21] (K+n).

5. Summary
In this paper we have presented a microscopic model for correlated 2π (and KK) exchange between kaon and nucleon, in the scalar-isoscalar (π) and vector-isovector (ρ) channels. We first constructed a model for the reaction \( N\pi \rightarrow K[\pi] \) with intermediate 2π and KK states, based on a transition in terms of baryon (N, A, A, ω) exchange and a realistic coupled channel \( \pi\pi \rightarrow \pi\pi, \pi\pi \rightarrow KK \) and KK \( \rightarrow KK \) amplitude. The contribution in the s-channel is then obtained by performing a dispersion relation over the unitarity cut.

In the o-channel, the result can be suitably represented by an exchange of a scalar

<table>
<thead>
<tr>
<th>Exp.</th>
<th>a0</th>
<th>a1</th>
<th>r0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.03 ± 0.15</td>
<td>-0.30 ± 0.03</td>
<td>0.43 ± 0.22</td>
</tr>
<tr>
<td>Model I</td>
<td>0.057</td>
<td>-0.316</td>
<td>0.373</td>
</tr>
<tr>
<td>Model I1 A</td>
<td>0.038</td>
<td>-0.304</td>
<td>0.261</td>
</tr>
<tr>
<td>Model I1 B</td>
<td>-0.080</td>
<td>-0.333</td>
<td>0.130</td>
</tr>
</tbody>
</table>

Empirical data are taken from Refs. [22,23].
Threshold ratios of the $K^-p$ system
R.J. Nowak et al., NPB 139 (1978) 61

\[
\gamma = \frac{\Gamma(K^-p \to \pi^+\Sigma^-)}{\Gamma(K^-p \to \pi^-\Sigma^+)} \\
R_c = \frac{\Gamma(K^-p \to \text{charged particles})}{\Gamma(K^-p \to \text{all})} \\
R_n = \frac{\Gamma(K^-p \to \pi^0\Lambda)}{\Gamma(K^-p \to \text{all neutral states})}
\]

Strong-interaction energy shift $\Delta E$ and the width $\Gamma$ of the 1s level of kaonic hydrogen - using the modified Deser-Trueman formula:

\[
\Delta E - \frac{i}{2} \Gamma = -2\alpha^3 \mu_{K^-p}^2 a_{K^-p} [1 - 2\alpha \mu_{K^-p} (\ln \alpha - 1) a_{K^-p}]
\]

→ JH, Krein, Meißner, Tolos, EPJA 47 (2011) 18
### KN results for the Jülich model

<table>
<thead>
<tr>
<th></th>
<th>Jülich model</th>
<th>experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>scattering lengths [fm]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a_{l=0}$</td>
<td>$-1.21 + i 1.18$</td>
<td></td>
</tr>
<tr>
<td>$a_{l=1}$</td>
<td>$1.01 + i 0.73$</td>
<td></td>
</tr>
<tr>
<td>$a_{K-p}$ ($l$)</td>
<td>$-0.10 + i 0.96$</td>
<td></td>
</tr>
<tr>
<td>$a_{K-p}$</td>
<td>$-0.36 + i 1.15$</td>
<td>$-0.65 \pm 0.10 + i 0.81 \pm 0.15$</td>
</tr>
<tr>
<td><strong>kaonic hydrogen</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>217 eV</td>
<td>$323 \pm 63 \pm 11$ eV [KEK]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$283 \pm 36 \pm 6$ eV [SIDDHARTA]</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>849 eV</td>
<td>$407 \pm 208 \pm 100$ eV [KEK]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$541 \pm 89 \pm 22$ eV [SIDDHARTA]</td>
</tr>
<tr>
<td><strong>threshold ratios</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>2.30</td>
<td>$2.36 \pm 0.04$ [Nowak]</td>
</tr>
<tr>
<td>$R_c$</td>
<td>0.65</td>
<td>$0.664 \pm 0.011$ [Nowak]</td>
</tr>
<tr>
<td>$R_n$</td>
<td>0.22</td>
<td>$0.189 \pm 0.015$ [Nowak]</td>
</tr>
<tr>
<td><strong>pole positions [MeV]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{01}$</td>
<td>$1435.8 - i 25.6$</td>
<td>$1405.1 \pm 1.3 - i 25 \pm 1$ [PDG]</td>
</tr>
<tr>
<td>$S_{01}$</td>
<td>$1334.3 - i 62.3$</td>
<td></td>
</tr>
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</table>
### Pole positions

<table>
<thead>
<tr>
<th>poles</th>
<th>interaction</th>
<th>NLO30</th>
</tr>
</thead>
<tbody>
<tr>
<td>1334 - i 62</td>
<td>Jülich</td>
<td></td>
</tr>
<tr>
<td>1381 - i 81</td>
<td>IHW</td>
<td></td>
</tr>
<tr>
<td>1355 - i 86</td>
<td>CS</td>
<td></td>
</tr>
<tr>
<td>1467 - i 75</td>
<td>MM</td>
<td></td>
</tr>
<tr>
<td>1436 - i 126</td>
<td>GO</td>
<td></td>
</tr>
<tr>
<td>1388 - i 114</td>
<td>GO</td>
<td></td>
</tr>
<tr>
<td>1352 - i 48</td>
<td>RO</td>
<td></td>
</tr>
<tr>
<td>1330 - i 56</td>
<td>MM [2015]</td>
<td></td>
</tr>
<tr>
<td>1390 - i 66</td>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>1379 - i 27</td>
<td>OM</td>
<td>LO</td>
</tr>
<tr>
<td>1321 - i 44</td>
<td>OPV</td>
<td>LO+B</td>
</tr>
<tr>
<td>1361 - i 30</td>
<td>OPV</td>
<td>A$_4^+$ (full)</td>
</tr>
</tbody>
</table>

- **IHW**: Ikeda, Hyodo, Weise - 2011;  
  **CS**: Cieply, Smekal - 2012  
- **MM**: Mai, Meißner - 2013,15;  
  **GO**: Guo, Oller - 2013;  
  **RO**: Roca, Oset - 2015  
- **OR**: Oset, Ramos - 1998;  
  **OM**: Oller, Meißner - 2001  
- **OPV**: Oller, Prades, Verbeni - 2005
is usually calculated from

\[
\frac{d\sigma}{dm_{\pi\Sigma}} = N \cdot |T_{\pi\Sigma \to \pi\Sigma}|^2 q_{\pi\Sigma}
\]

utilizing just the isospin \( I = 0 \) amplitude.

but for a realistic comparison

\[
\frac{d\sigma}{dm_{\pi\Sigma}} = \sum_{X=\bar{K}N,\pi\Lambda,\pi\Sigma} N_X \cdot |T_{X \to \pi\Sigma}|^2 q_{\pi\Sigma}
\]

and \( \pi\Sigma = \pi^+\Sigma^- \), \( \pi^0\Sigma^0 \), or \( \pi^-\Sigma^+ \)

\( \to I = 1 \) amplitude contributes with different weight, e.g.

\[
T_{pK^- \to \Sigma^+\pi^-} = \frac{1}{2} T_{NK \to \Sigma\pi}^{1} + \frac{1}{\sqrt{6}} T_{NK \to \Sigma\pi}^{0}
\]

\[
T_{pK^- \to \Sigma^0\pi^0} = -\frac{1}{\sqrt{6}} T_{NK \to \Sigma\pi}^{0}
\]

\[
T_{pK^- \to \Sigma^-\pi^+} = -\frac{1}{2} T_{NK \to \Sigma\pi}^{1} + \frac{1}{\sqrt{6}} T_{NK \to \Sigma\pi}^{0}
\]
\[ T_{\pi \Sigma}(q) = -\exp(i\delta(q)) \sin(\delta(q))/q \]
\[ |T_{\pi \Sigma}|^2 \cdot q = \sin^2(\delta(q))/q \]
Invariant mass distributions

πΣ \rightarrow πΣ

\bar{K}N \rightarrow πΣ

R.J. Hemingway (1985): M(Σ^- π^+), M(Σ^+ π^-)
Information on the strength of the $\pi\Sigma$ interaction (scattering length) would provide further constraints for

- existence of deeply bound $\bar{K}$ states
- sub-threshold $\bar{K}N$ amplitude

→ possible determination of $a_{\pi\Sigma}$ from precise data of the $\pi\Sigma$ spectrum (CLAS, ELSA, HADES, COSY, ...)

<table>
<thead>
<tr>
<th></th>
<th>Oset-Ramos</th>
<th>Y. Ikeda et al.</th>
<th>Jülich</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A2</td>
<td>B E-dep</td>
</tr>
<tr>
<td>pole 1</td>
<td>1426 - i 16</td>
<td>1425 - i 11</td>
<td>1422 - i 22</td>
</tr>
<tr>
<td>pole 2</td>
<td>1390 - i 66</td>
<td>1321</td>
<td>1349 - i 54</td>
</tr>
<tr>
<td>$a_{\pi\Sigma}$ [fm]</td>
<td>0.789</td>
<td>-2.30</td>
<td>1.44</td>
</tr>
<tr>
<td>$a_{\bar{K}N}$ [fm]</td>
<td>-1.65+1.089</td>
<td>-1.70+0.68</td>
<td>-1.70+0.68</td>
</tr>
</tbody>
</table>
The $DN$ and $\bar{D}N$ interactions

**Theoretical studies** of the $DN$ and $\bar{D}N$ interaction

- **Effective SU(4) hadronic Lagrangian; based on $\rho$ exchange; Born approximation**
  
  Z.-W. Lin et al., PRC 61 (2000) 024904

- **Phenomenological (separable) coupled-channels model (for $DN$ system)**
  
  L. Tolós et al., PRC 70 (2004) 025203

- **Chiral Lagrangians; unitarization**
  
  J. Hofmann & M.F.M. Lutz, NPA 763 (2005) 90
  L. Tolós et al., PRC 77 (2008) 015207
  C. Garcia-Recio et al., PRD 79 (2009) 054004
  W.H. Liang et al., EPJA 51 (2015) 16
**Mesonic sector:** working hypothesis SU(4) symmetry

\[
g_{\bar{D}D\rho} = g_{DD\rho} = g_{KK\rho} \\
g_{\bar{D}D\omega} = -g_{DD\omega} = g_{KK\omega}
\]

**Scalar mesons** \((S=\sigma, a_0)\): member of a SU(3) multiplet? 
what is the \(\sigma_{\text{rep}}\)?
in the Jülich model: \(g_{D\bar{D}S} (g_{KKS}) \cong \text{correlated } \pi\pi/K\bar{K}/\bar{D}D \text{ exchange} \)

\[
\begin{array}{c}
\begin{array}{c}
\bar{K} \bullet \\
\rho \bullet \\
N \bullet \\
\end{array}
\begin{array}{c}
\pi \bullet \\
\pi \bullet \\
\pi \bullet \\
\end{array}
\end{array}
\begin{array}{c}
\begin{array}{c}
\bar{K} \bullet \\
\rho \bullet \\
N \bullet \\
\end{array}
\begin{array}{c}
\pi \bullet \\
\pi \bullet \\
\pi \bullet \\
\end{array}
\end{array}
\begin{array}{c}
\begin{array}{c}
D \bullet \\
D^* \bullet \\
N \bullet \\
\end{array}
\begin{array}{c}
\pi \bullet \\
\pi \bullet \\
\pi \bullet \\
\end{array}
\end{array}
\end{array}
\]

\((a) \quad (b) \quad (c)\)

in practice: fix coupling constants of **scalar** mesons by a fit to data 
⇒ fine-tune coupling constants of **scalar** mesons to the mass of \(\Lambda_c(2595)\)
form factors at the **meson-meson-meson vertices** are taken over from $KN$ ($\bar{K}N$)

most baryon-baryon-meson vertices are the same as in $KN$ ($\bar{K}N$)!

$\Rightarrow$ take over coupling constants and form factors

for vertices involving $\Lambda_c$ and/or $\Sigma_c$ SU(4) is invoked

- $KN$ and $\bar{K}N$ ($\bar{D}N$ and $DN$) connected by G-parity
Dynamics

$D \pi, \rho, \omega$

$D^* \pi, \rho$

$\rho, \omega$

$\pi, \rho$

$\sigma, \omega$

$\Delta$

$\Lambda_c, \Sigma_c$

$\Lambda_c, \Sigma_c$

$\Sigma_c, \Lambda_c$

$\Sigma_c [\Lambda_c]$

$\Sigma_c [\Lambda_c]$

$\Lambda_c, \Sigma_c$

$\Lambda_c, \Sigma_c$
The **$DN$ channel**

Jülich $\bar{K}N$ model: those channels that are open at the $\bar{K}N$ threshold are taken into account

- model predicts the $\Lambda(1405)$ to be a quasibound $\bar{K}N$ state!

$DN$:

include likewise the coupling to those channels that are open at threshold

$\rightarrow \pi\Lambda_c(2285)$ and $\pi\Sigma_c(2455)$

- model generates quasibound $DN$ states in $S_{01}$, $S_{11}$ and $P_{01}$ partial waves ($L_{I2J}$)

$\Rightarrow$ identify $S_{01}$ state with $\Lambda_c(2595)$, and $S_{11}$ state with $\Sigma_c(2800)$ (fine tuning is needed to reproduce masses quantitatively!)

$P_{01}$ state $\rightarrow \Lambda_c(2765)$ ?
### Scattering lengths

<table>
<thead>
<tr>
<th></th>
<th>meson-exchange model</th>
<th>SU(4) WT $DN$ model(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>scattering lengths [fm]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a_{I=0}$</td>
<td>$-0.41 + i 0.04$</td>
<td>$-0.57 + i 0.001$</td>
</tr>
<tr>
<td>$a_{I=1}$</td>
<td>$-2.07 + i 0.57$</td>
<td>$-1.47 + i 0.65$</td>
</tr>
<tr>
<td><strong>pole positions [MeV]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{01}$</td>
<td>2593.9 - i 2.88</td>
<td>2595.4 - i 1.0</td>
</tr>
<tr>
<td>$S_{01}$</td>
<td>2603.2 - i 63.1</td>
<td>2625.4 - i 51.5</td>
</tr>
<tr>
<td>$S_{01}$</td>
<td>2694.7 - i 76.5</td>
<td></td>
</tr>
<tr>
<td>$S_{11}$</td>
<td>2797.3 - i 5.86</td>
<td>2661.2 - i 18.2</td>
</tr>
<tr>
<td>$P_{01}$</td>
<td>2804.4 - i 2.04</td>
<td></td>
</tr>
</tbody>
</table>

(*) T. Mizutani, A. Ramos, PRC 74 (2006) 065201

PDG: $2592.25 \pm 0.28$ MeV, $\Gamma/2 = 1.3 \pm 0.3$ MeV; ($\Sigma^{++}_c$) $2801 \pm 4$ MeV, $\Gamma/2 \approx 37.5 \pm 10$ MeV
Cross sections

\[ \sigma_{\text{tot}} \text{ (mb)} \]

\[ S^{1/2} - m_N - m_D \text{ (MeV)} \]

- Jülich \( DN \) model
- - - WT SU(4) - Mizutani, Ramos
- - Jülich \( \bar{K}N \) model

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\( DN \) and \( \bar{K}N \) interactions
a) $D^0 n \rightarrow D^0 n$ (– –)
b) $D^0 p \rightarrow D^0 p$ (—)
c) $D^0 p \rightarrow D^+ n$ (·—)
Invariant mass distributions

\[ \pi \Sigma_c \rightarrow \pi \Sigma_c \]

\[ DN \rightarrow \pi \Sigma_c \]

$S_{01}$ Phase shifts

\[ \pi \Sigma \]

\[ \pi \Sigma_c \]

\[ \delta \text{ (degrees)} \]

\[ s^{1/2} \text{ (MeV)} \]

--- Jülich $DN$ model; --- WT SU(4) - Mizutani, Ramos

Johann Haidenbauer  
$DN$ and $\bar{K}N$ interactions
Jülich meson-exchange potential for $\bar{K}N$ (Müller-Groehling, 1990)

- near-threshold elastic and inelastic $\bar{K}N$ scattering data are well reproduced
- deficiencies in the energy shift $\Delta E$ and the width $\Gamma$ of the $1s$ level of kaonic hydrogen
- the $\Lambda(1405)$ resonance is generated dynamically
- predicts two poles in the $S$-wave with isospin $I = 0$

Predictions for $\bar{D}N$ and $DN$ within the meson-exchange picture

- model is constructed in close analogy to the Jülich $KN$ and $\bar{K}N$ potentials utilizing SU(4) symmetry
- cross sections are comparable (somewhat larger) than those for $KN$
- cross sections are of the same order as predicted by other approaches to $\bar{D}N$ ($DN$)
- three states ($\Lambda_c(2595), \Sigma_c(2800), \Lambda_c(2765)$) are generated dynamically
Proposal for the J-PARC 50-GeV Proton Synchrotron
(Proposal E31, S. Ajimura et al., July 2012)

Spectroscopic study of hyperon resonances below $\bar{K}N$ threshold via the $(K^-, n)$ reaction on the deuteron
perform measurement at $p_{K^-} \approx 800$ MeV/c and $\theta_n = 0 - 5^\circ$

- primary goal: study the position and width of the $\Lambda(1405)$ resonance produced in the $\bar{K}N \to \pi\Sigma$ channel

$\Rightarrow$ calculate $K^- d \to \pi\Sigma n$ within a Faddeev-type approach utilizing

- Jülich $\bar{K}N$ potential
- Oset-Ramos chiral potential
- other more recent $\bar{K}N$ interactions

K. Miyagawa and JH, PRC 85 (2012) 065201 [one- and two-step processes only]
Main contribution comes from (B2)  

⇒ signal from $\Lambda(1405)$ in $K^- d \rightarrow \pi \Sigma n$ is weak - but disputed by Jido et al.
Faddeev calculation

Coupled with 2-body interaction
Isospin interaction

$K^- p n - \bar{K}^0 n n$
processes

$K^- p n - \bar{K}^0 n n$
treat $\bar{K}NN$ in three-body framework

$5 \text{ MeV}$

$T = 1$

$T = 0, 1$

$\text{Coupled with 2-body interaction}$
preliminary results

$K^- d \rightarrow \pi \Sigma n$ invariant mass spectrum

$P_{K^-} = 800$ MeV/c
$\theta_n = 0^\circ$

$P_{K^-} = 1000$ MeV/c
$\theta_n = 0^\circ$

K. Miyagawa, J.H., in preparation