Effective model for $\overline{K}N$ interactions including the $L = 1$ partial wave

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RIKEN's Programs for Junior Scientists

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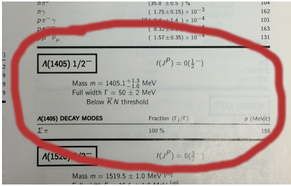
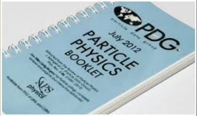
based on A. Cieplý, V.K., arXiv:1501.06415 [nucl-th] (2015)
V.K., Phys. Rev. C 86, 024003 (2012)

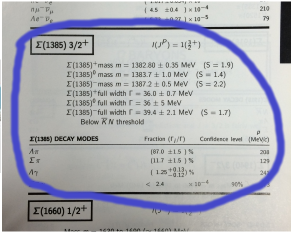
strange $S = -1$ meson-baryon interactions

- **strongly coupled multichannel system**

channel	:	$\pi\Lambda$	$\pi\Sigma$	$\overline{K}N$	$\eta\Lambda$	$\eta\Sigma$	$K\Xi$
threshold [MeV]	:	1250	1330	1435	1660	1740	1810





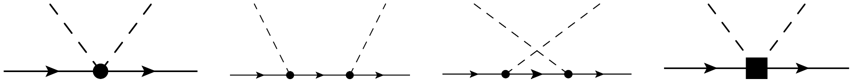


$\Lambda(1405)$ in the S-wave and isospin $I = 0$ channel

$\Sigma(1385)$ in the P-wave and isospin $I = 1$ channel

- **resonances are present below the $\overline{K}N$ threshold**

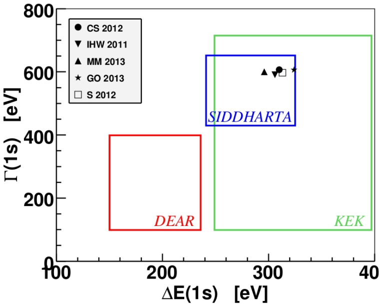
state of the art — S-wave



$\mathcal{O}(q^1)$-constact $\mathcal{O}(q^2)$-direct $\mathcal{O}(q^2)$-crossed $\mathcal{O}(q^2)$-constact

constructed from 2nd order chiral Lagrangian

- parameters fit to *scattering data, threshold branching ratios, kaonic hydrogen*



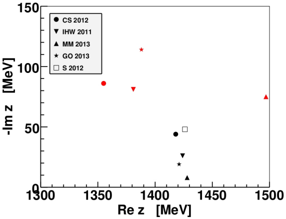
courtesy of A. Cieplý

- CS2012 - Cieplý, Smejkal, NPA 881 (2012)
- IHW2011 - Ikeda, Hyodo, Weise, NPA 881 (2012)
- MM2013 - Mai, Meißner, NPA 890 (2013)
- GO2013 - Guo, Oller, PRC 87 (2013)

$\Lambda(1405)$ resonance generated dynamically

TWO POLES

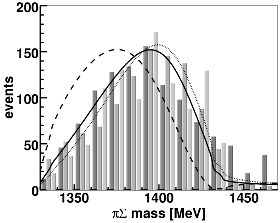
relative agreement on the position of the $\overline{K}N$ related pole, the position of the $\pi\Sigma$ related pole much less constrained



$\pi\Sigma$ MASS SPECTRUM

different experiments (CLAS, ANKE, HADES) exhibit slightly different curves

depends on the reaction mechanism



courtesy of A. Cieplý

Why bother with the P-wave?

- **things get entangled in the nuclear medium**

6. $\Sigma^+\pi^-$ invariant mass and momentum spectra

After the identification of the Σ^+ signal, the final $\Sigma^+\pi^-$ invariant mass and momentum spectra can be constructed. The plots are shown in fig. 8.

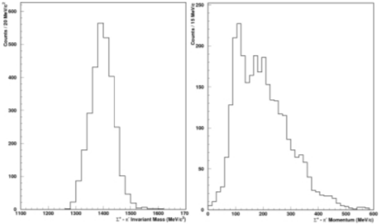


Figure 8: The final $\Sigma^+\pi^-$ invariant mass (left) and momentum (right) spectra.

It is important to notice that these final plots do not represents the "pure" $\Lambda(1405)$ resonance mass and momentum, since they are affected by the presence of the $\Sigma(1385)$ resonance and of the non-resonant K^-p interaction events, whose contribution has to be disentangled. The momentum spectrum shows two components around 100 MeV/c and 200 MeV/c; this is in complete agreement with the results obtained in the analysis of the $\Sigma^0\pi^0$ channel performed on the same data [6], where these two components have been demonstrated to correspond respectively to in flight and at rest K^-p interactions.

A. Scordo** et al. **[AMADEUS Collaboration], arXiv:1304.7149 [nucl-ex].

three independent partial waves:

$L = 0,\ J = \frac{1}{2}$ .... $\mathbf{0}^+$

$L = 1,\ J = \frac{1}{2}$ .... $\mathbf{1}^-$

$L = 1,\ J = \frac{3}{2}$ .... $\mathbf{1}^+$

as long as the interaction is parity and time reversal invariant!

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potentials in the separable form:

$$V^{l\pm}_{(ai)\to(bj)}(p,p') = g^{l}_{(ai)}(p)\ \ v^{l\pm}_{(ai)\to(bj)}\ \ g^{l}_{(bj)}(p')$$

$v^{l\pm}_{(ai)\to(bj)}$ is a coupling matrix where the inter-channel dynamics is encoded.

$$g^{0}_{(ai)}(p) = 1 \Bigg/ \left(1 + \frac{p^2}{\alpha^2_{(ai)}}\right) \qquad g^{1}_{(ai)}(p) = p \Bigg/ \left(1 + \frac{p^2}{\alpha^2_{(ai)}}\right)^{3/2}$$

effective model — general formulation

three separate Lippmann-Schwinger Equations:

$$
\begin{aligned}
F^{0+} &= V^{0+} + V^{0+}\, G^{0}\, F^{0+} \\
F^{1-} &= V^{1-} + V^{1-}\, G^{1}\, F^{1-} \\
F^{1+} &= V^{1+} + V^{0+}\, G^{1}\, F^{1+}
\end{aligned}
$$

Green function in *the vacuum*:

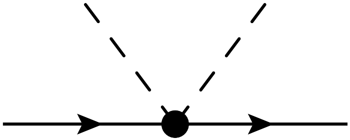
$$
G^{l}_{(ck)}(\sqrt{s}) = -\frac{1}{2\pi^2} \int \mathrm{d}^3 q \frac{\left(g^{l}(q)\right)^2}{p^2_{(ck)} - q^2 + i\epsilon}
$$

Green function in *the nuclear medium*:

$$
G^{l}_{(ck)}(\sqrt{s},\, \rho) = -\frac{1}{2\pi^2} \int_{\Omega_{(ck)}(\rho)} \mathrm{d}^3 q \frac{\left(g^{l}(q)\right)^2}{p^2_{(ck)} - q^2 - \Pi_{(ck)}(\sqrt{s}, p, \rho) + i\epsilon}
$$

$\Omega_{(ck)}(\rho)$ integration domain determined by the Pauli blocking, and $\Pi_{(ck)}(\sqrt{s}, p, \rho)$ selfenergy

S-WAVE POTENTIAL



Weinberg-Tomozawa only

parameters TW1 determined
by Cieplý, and Smejkal (2012)

S-wave potential

free parameters:

meson decay constant $\boxed{f_\pi}$, **one range parameter** $\boxed{\alpha}$

experimental data:

- *kaonic hydrogen (SIDDHARTA)*
  - shift $\Delta E_N(1s) = 283 \pm 36\,(stat.) \pm 6\,(syst.)\mathrm{eV}$
  - width $\Gamma(1s) = 541 \pm 89\,(stat.) \pm 22\,(syst.)\mathrm{eV}$
- *K^-p threshold branching ratios*
  - $\gamma_p = \frac{\sigma(K^-p\to\pi^+\Sigma^-)}{\sigma(K^-p\to\pi^-\Sigma^+)}$ $R_c = \frac{\sigma(K^-p\to\mathrm{charged})}{\sigma(K^-p\to\mathrm{all})}$ $R_n = \frac{\sigma(K^-p\to\pi^0\Lambda)}{\sigma(K^-p\to\mathrm{neutral})}$
- *low energy K^-p cross sections*

results of the S-wave fit:

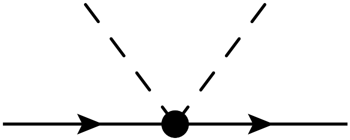
$$f_\pi = 113\,\mathrm{MeV},\ \alpha = 701\,\mathrm{MeV}$$

A. Cieplý, J. Smejkal, Nucl. Phys. A 881 (2012).

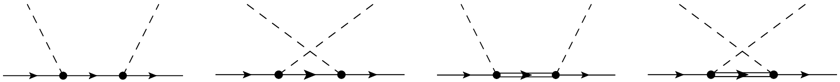
S-WAVE POTENTIAL

Weinberg-Tomozawa only

parameters TW1 determined
by Cieplý, and Smejkal (2012)

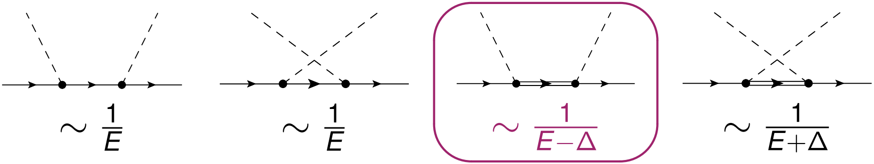


P-WAVE POTENTIAL



in principle four different contributions

P-wave potential



$\Sigma(1385)$ dominates the P-wave physics!

How to determine the meson-baryon-baryon coupling?

Follow the large N_c limit of QCD!! is one option.

at large N_c, octet and decuplet baryons are created equal
(rigorously speaking, the belong to the same ground state multiplet)

P-wave potential

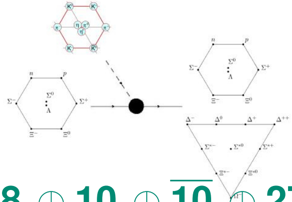
key formal features of large N_c χPT:

- **consistency relations; the contracted $SU(2N_f)$ symmetry**

practical meaning:

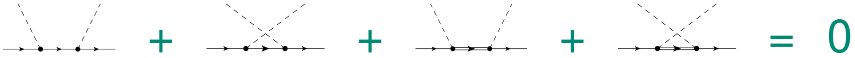
- **relative couplings given by CG coefficients**

$$\frac{\partial^i \phi^a}{f_\pi} \left\langle B' \right| \sigma^i \lambda^a \left| B \right\rangle \sim$$



$$\mathbf{8} \otimes \mathbf{8} = \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}$$

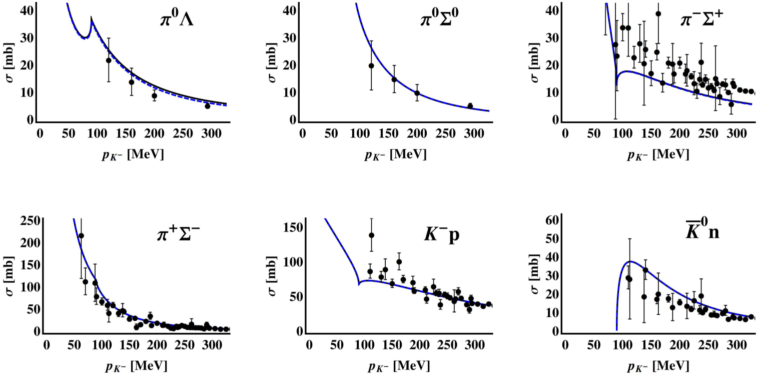
- **vanishing πN scattering determines the strength**



- diagrams **determined** by scaling — $\Sigma(1385)$ dominant
- coupling matrix **determined** using large N_c motivation
- bare mass of the $\Sigma(1385)$ **determined** to match its physical mass
- free parameters **determined** by the S-wave analysis

NO ADDITIONAL FREEDOM !!

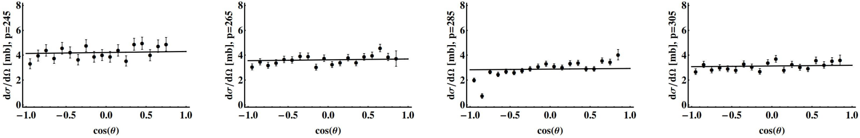
- $K^- p \to \ldots$ total cross sections



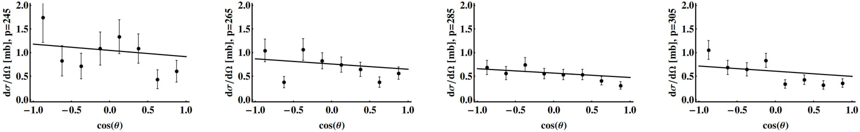
the effect of the P-wave is marginal

vacuum results

- $K^- p \to K^- p$ differential cross section



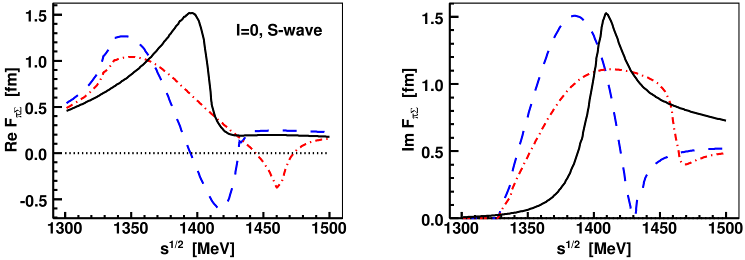
- $K^- p \to \overline{K}^0 n$ differential cross section



the slope direction well reproduced, the slope angle better for $\overline{K}^0 n$ transition

- $\pi\Sigma$ amplitude in the S-wave

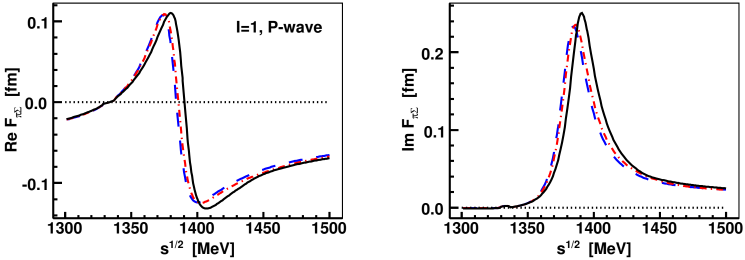
dashed ***free space****, dot-dashed* ***+Pauli blocking****, full* ***+selfenergies***



$\Lambda(1405)$ **dissolves in the nuclear medium and shifts its position**

- $\pi\Sigma$ amplitude in the P-wave

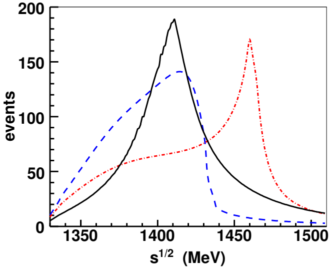
*dashed **free space**, dot-dashed **+Pauli blocking**, full **+selfenergies***



effects of the nuclear medium on $\Sigma(1385)$ **are quite limited**

- $\pi\Sigma$ mass distribution

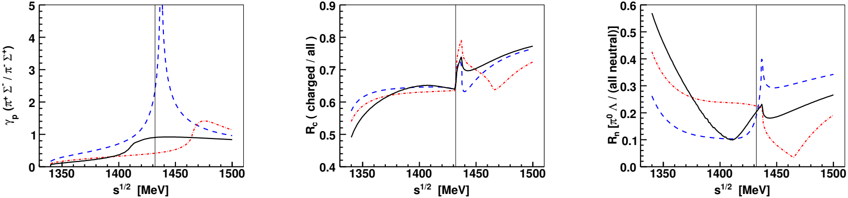
*dashed **free space**, dot-dashed **+Pauli blocking**, full **+selfenergies***



the in-medium peak is much narrower than in the vacuum

- threshold branching ratios

dashed ***free space****, dot-dashed* ***+Pauli blocking****, full* ***+selfenergies***



$$\gamma_p = \frac{\sigma(K^- p \to \pi^+ \Sigma^-)}{\sigma(K^- p \to \pi^- \Sigma^+)} \qquad R_c = \frac{\sigma(K^- p \to \text{charged})}{\sigma(K^- p \to \text{all})} \qquad R_n = \frac{\sigma(K^- p \to \pi^0 \Lambda)}{\sigma(K^- p \to \text{neutral})}$$

see the peak in the γ_p energy dependence

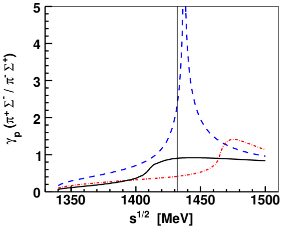
isospin decomposition

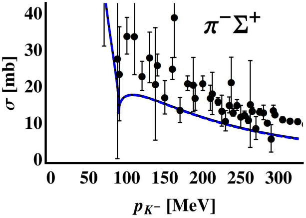
$$| K^- p\rangle \sim \sqrt{\frac{1}{2}} \, | \bar{K}N\rangle_{I=0} - \sqrt{\frac{1}{2}} \, | \bar{K}N\rangle_{I=1}$$

$$\langle \pi^- \Sigma^+ | \sim -\sqrt{\frac{1}{3}} \langle \pi\Sigma |_{I=0} + \sqrt{\frac{1}{2}} \langle \pi\Sigma |_{I=1}$$

$$\langle \pi^+ \Sigma^- | \sim -\sqrt{\frac{1}{3}} \langle \pi\Sigma |_{I=0} - \sqrt{\frac{1}{2}} \langle \pi\Sigma |_{I=1}$$

$$\gamma_p = \frac{\left| T_0 + \sqrt{\frac{3}{2}} T_1 \right|^2}{\left| T_0 - \sqrt{\frac{3}{2}} T_1 \right|^2}$$





denominator suppression due to T_1-T_0 interference, peak at $\overline{K}^0 n$ threshold

conclusions

- **the effective model for $\overline{K}N$ was extended to include P-wave physics**
- **reasonable description of the vacuum data; suitable for the in-medium analysis**
- **future – more involved EFT backed model**
  lattice QCD calculation

work was supported by RIKEN programs for junior scientists