Updated study of meson-baryon dynamics with strangeness –1 in a chiral framework

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Outline

1. Background and motivation
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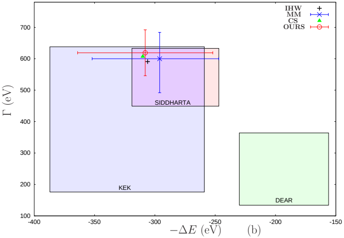
Background and motivation

Interests in S-wave meson-baryon scattering with strangeness -1:

- $\Lambda(1405)$: a baryon resonance below $\bar{K}N$ threshold, two-pole structure, ...
- Status of experiments on the energy shift and width of the $1s$ kaonic hydrogen state: KEK, DEAR and SIDDHARTA



$$\Delta E - i\frac{\Gamma}{2} = -2\alpha^3\,\mu_r^2\,a_{K^-p}$$
$$\left[1 + 2\alpha\,\mu_r\,(1 - \ln\alpha)\,a_{K^-p}\right],$$

$\mu_r = m_p M_{K^-}/(M_{K^-} + m_p)$,
a_{K^-p} the scattering length
[Meissner,Raha,Rusetsky, '04EPJC]

- Controversial and active study for $\bar{K}$-nuclear systems: $\bar{K}N$ scattering below threshold is crucial
- Provide important ingredients for strangeness photoproduction

Theoretical formalism:

Chiral Perturbation Theory plus unitarity

$$\begin{aligned}\mathcal{L}_1 = \quad & \langle i\bar{B}(\gamma^\mu[D_\mu, B]\rangle - m_0\langle\bar{B}B\rangle \\ & +\frac{D}{2}\langle\bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}\rangle + \frac{F}{2}\langle\bar{B}\gamma^\mu\gamma_5[u_\mu, B]\rangle\,, \\ \mathcal{L}_2 = \quad & b_0\langle\bar{B}B\rangle\langle\chi_+\rangle + b_D\langle\bar{B}\{\chi_+, B\}\rangle + b_F\langle\bar{B}[\chi_+, B] \\ & +b_1\langle\bar{B}[u_\mu, [u^\mu, B]]\rangle\rangle + b_2\langle\bar{B}\{u_\mu, \{u^\mu, B\}\}\rangle \\ & +b_3\langle\bar{B}\{u_\mu, [u^\mu, B]\}\rangle + b_4\langle\bar{B}B\rangle\langle u_\mu u^\mu\rangle + \cdots\end{aligned}$$

with $U = u^2 = e^{i\Phi/f}$, $u_\mu = iu^\dagger(\partial_\mu U)u^\dagger$

$$B = \begin{pmatrix} \frac{\Sigma_0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma_0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}, \quad \Phi = \begin{pmatrix} \frac{\pi_0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi_0}{\sqrt{2}} + \frac{\eta_8}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{2\eta_8}{\sqrt{6}} \end{pmatrix}$$

Relevant Feynman diagrams

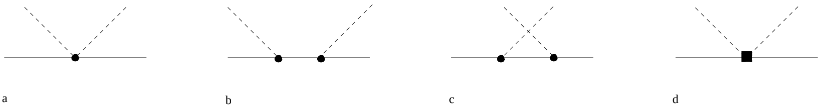


Figure: Meson-baryon scattering amplitudes (V_{ij}) up to next-to-leading order: vertexes in (a)(b)(c) are from $\mathcal{L}_1$ and vertexes in (d) are from $\mathcal{L}_2$.

Partial wave projection

We focus on the S-wave meson-baryon scattering:

$$\mathcal{T}_{ij}(W=\sqrt{s}) = \frac{1}{4\pi}\int d\Omega\, V_{ij}(W,\Omega,\sigma_3,\sigma_3)\,.$$

V_{ij} stand for the meson-baryon $(\phi B)_i \to (\phi B)_j$ scattering amplitudes, with the labels $i,j = 1,2,3,\ldots,10$ corresponding to the ten different channels: $\pi^0\Lambda$ (1), $\pi^0\Sigma^0$ (2), $\pi^-\Sigma^+$ (3), $\pi^+\Sigma^-$ (4), K^-p (5), $\bar{K}^0 n$ (6), $\eta\Lambda$ (7), $\eta\Sigma^0$ (8), $K^0\Xi^0$ (9) and $K^+\Xi^-$ (10).

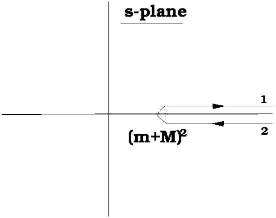
Unitarity in partial wave amplitudes

- Crucial for $\bar{K}N$ scattering: breakdown of the perturbative treatment of chiral amplitudes, e.g. appearance of $\Lambda(1405)$
- Starting point: unitarity condition of a partial wave

$$\mathrm{Im}\, T_{ij}(s) = \sum_k T_{ik}\rho_k T^*_{kj} \Rightarrow \mathrm{Im}\, T^{-1}_{ij}(s) = -\rho_i(s)\delta_{ij}\,, \quad s > s_{\mathrm{th}}$$

with $\rho_i = \frac{q_i}{8\pi\sqrt{s}} = \frac{\sqrt{[s-(m+M)^2][s-(m-M)^2]}}{16\pi s}$.

- Dispersion relation for T^{-1}



$$T^{-1}_{ij}(s) = N^{-1}_{ij}(s)$$
$$\underbrace{+\delta_{ij}\left[a^{SL}(s_0) - \frac{s-s_0}{\pi}\int_{s_{\mathrm{th}}}^{\infty}\frac{\rho(s')}{(s'-s)(s'-s_0)}ds'\right]}_{\displaystyle \Downarrow \atop \displaystyle g_{ij}(s)}$$

$g(s)$ function corresponds to two-point loop function and dimensional regularization leads to

$$16\pi^2 g(s) = a_{SL}(\mu) + \log\frac{m_b^2}{\mu^2} - x_+ \log\frac{x_+ - 1}{x_+} - x_- \log\frac{x_- - 1}{x_-},$$

$$x_\pm = \frac{s + m_a^2 - m_b^2}{2s} \pm \frac{1}{-2s}\sqrt{-4s(m_a^2 - i0^+) + (s + m_a^2 - m_b^2)^2},$$

and subtraction constants a_{SL} will be fitted to data.

- Unitarized partial wave amplitude

[Oller, Oset, PRD'99]

$$T(s) = \left[N^{-1}(s) + g(s)\right]^{-1} = \left[I + N(s)\cdot g(s)\right]^{-1}\cdot N(s)$$

Through the chiral expansion and matching with perturbative χPT amplitudes, one can obtain

$$N_1 = T_1^{\chi PT}, \qquad N_2 = T_2^{\chi PT},$$
$$N_3 = T_3^{\chi PT} + T_1^{\chi PT}\cdot g(s)\cdot T_1^{\chi PT}, \quad \cdots\cdots$$
$$N = N_1 + N_2 + N_3 + \cdots$$

Phenomenological discussions

Data included in our fits:

- Cross sections at low energy:
  $K^- p \to K^- p, \bar{K}^0 n, \pi^+\Sigma^-, \pi^-\Sigma^+, \pi^0\Sigma^0, \pi^0\Lambda, \eta\Lambda$

$$\sigma[(\phi B)_i \to (\phi B)_j] = \frac{1}{16\pi\, s} \frac{|\vec{p}_j|}{|\vec{p}_i|} \left| T_{(\phi B)_i \to (\phi B)_j} \right|^2 .$$

- Ratios at threshold

$$\gamma = \frac{\sigma(K^- p \to \pi^+\Sigma^-)}{\sigma(K^- p \to \pi^-\Sigma^+)} , \quad R_c = \frac{\sigma(K^- p \to \text{charged particles})}{\sigma(K^- p \to \text{all})} ,$$

$$R_n = \frac{\sigma(K^- p \to \pi^0\Lambda)}{\sigma(K^- p \to \text{all neutral states})} .$$

- SIDDHARTA measurements on the width (Γ) and energy shift (ΔE) of kaonic hydrogen state
- $\pi\Sigma$ event distribution from the process $K^- p \to \Sigma^+(1660)\pi^-$
- $K^- p \to \pi^0\pi^0\Sigma^0$: total cross section and $\pi^0\Sigma^0$ event distribution
- $\pi\Lambda$ phase difference between P- and S-wave at the m_{Ξ^-}: $\delta_{\pi\Lambda}$
- Next-to-leading order fits of $\sigma_{\pi N}, a^+_{0+}, m_N, m_\Lambda, m_\Sigma, m_\Xi$

Two sources of uncertainties are investigated carefully, which are overlooked in previous works:

1. Employ a common decay constant f for π, K, η: **Fit-I**,
   [Kaiser,Siegel,Weise,'95],[Magas,Oset,Ramos,'05],[Oller,Meissner,'01]
   [Borasoy,Nissler,Weise,'05'06],[Garcia-Recio, *et al.*,'03]
   or distinguish the values of f_π, f_K, f_η: **Fit-II**
   [Nieves,Ruiz Arriola,'01],[Ikeda,Hyodo,Weise,'11'12],[Mai,Meissner,'13]
2. Influence of different strategies to define the χ^2 in the fit:
   Standard definition for χ^2

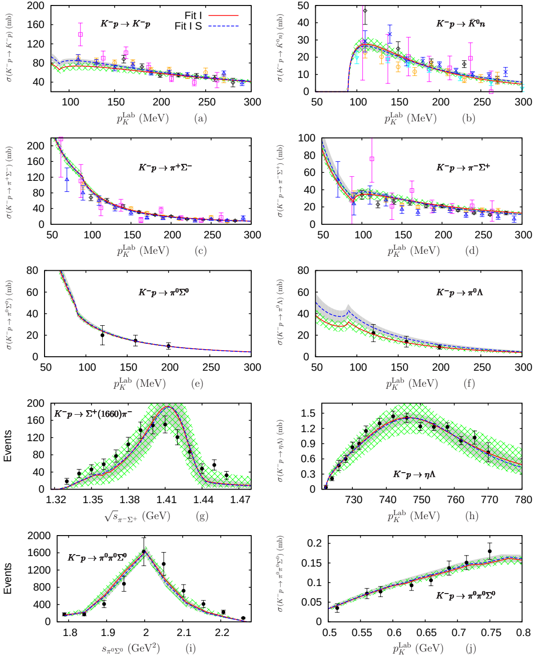
$$\chi^2_{d.o.f} = \frac{1}{\sum_k n_k - n_p} \sum_{k=1}^{L} \chi_k^2 \ ,$$

[Oller,Meissner,'01],[Jido,*et al.*,'03],[Oller,'06]

Weight-averaged χ^2

$$\chi^2_{d.o.f} = \frac{\sum_k n_k}{L\,(\sum_k n_k - n_p)} \sum_{k=1}^{L} \frac{\chi_k^2}{n_k} \ , \quad \chi_k^2 = \sum_{i=1}^{n_k} \frac{\left(y_{k;i}^{th} - y_{k;i}^{exp}\right)^2}{\sigma_{k;i}^2} \ .$$

[Garcia-Recio,*et al.*,'03],[Borasoy,Nissler,Weise,'05'06]
[Ikeda,Hyodo,Weise,'11'12],[Mai,Meissner,'13]

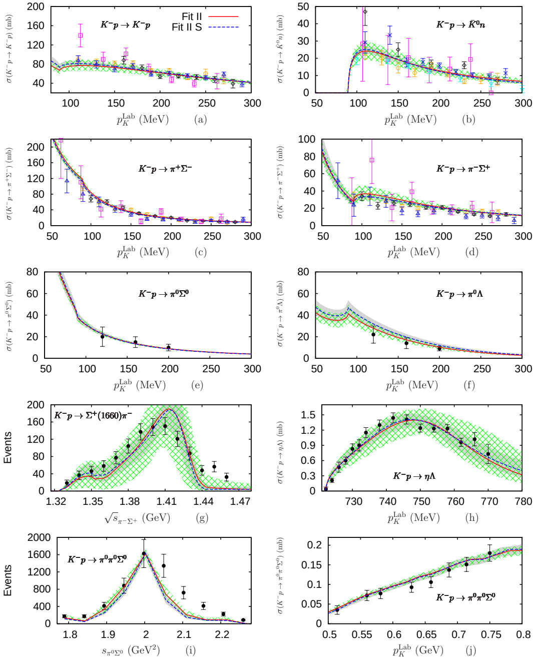


Fit-I (weighted χ^2)

Fit-I-S (standard definition for χ^2)

Fit-I: a common decay constant f for all the channels

[Guo, Oller, '13PRC]



Fit-II (weighted χ^2)

Fit-II-S (standard definition for χ^2)

Fit-II: distinguish f_π, f_K, f_η

[Guo, Oller, '13PRC]

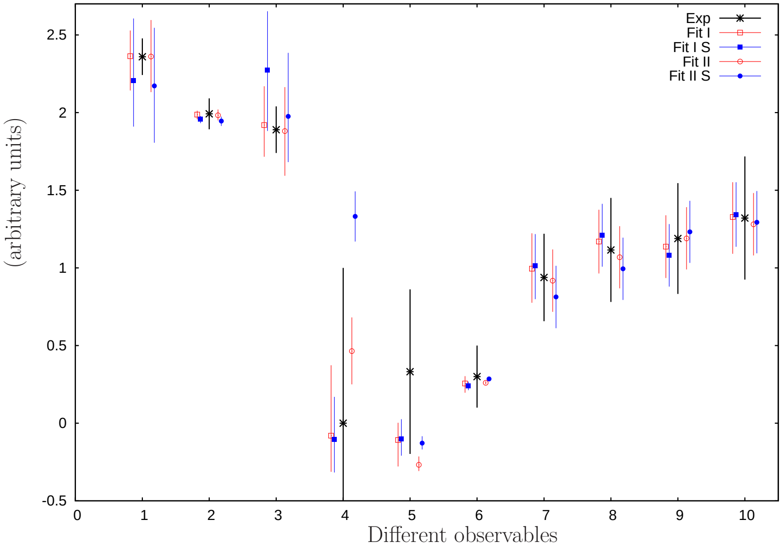


Figure: 1–10: γ, R_c, R_n, a_{0+}^{+}, $\delta_{\pi\Lambda}$, $\sigma_{\pi N}$, m_N, m_Λ, m_Σ and m_Ξ

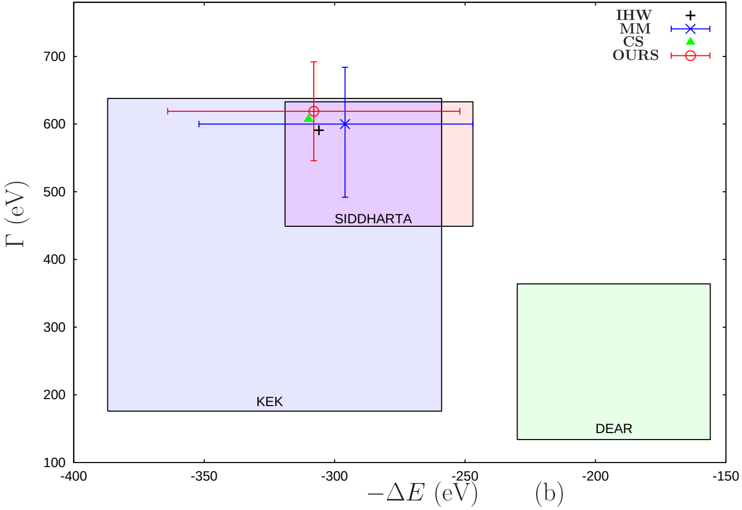


Figure: Energy shift and width of kaon hydrogen 1s state. IHW: [Ikeda, Hyodo and Weise, '11'12], MM: [Mai and Meissner,'13], CS: [Cieply and Smejkal,'12]

Scattering lengths (fm)

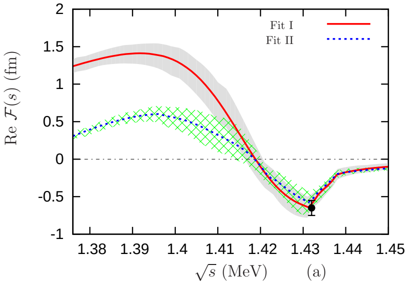
This work: [Guo, Oller, '13PRC]
$a_{K^-p} = (-0.69^{+0.16}_{-0.16}) + i\,(0.94^{+0.11}_{-0.11})$

Comparison with other recent determinations:

[Ikeda, Hyodo, Weise, '12NPA]:
$a_{K^-p} = (-0.70^{+0.13}_{-0.13}) + i\,(0.89^{+0.16}_{-0.16})$

[Mai, Meissner, '13NPA]:
$a_{K^-p} = (-0.68^{+0.18}_{-0.17}) + i\,(0.90^{+0.13}_{-0.13})$

$\bar{K}N$ scattering amplitudes in subthreshold region



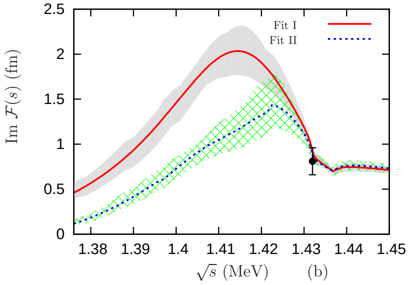
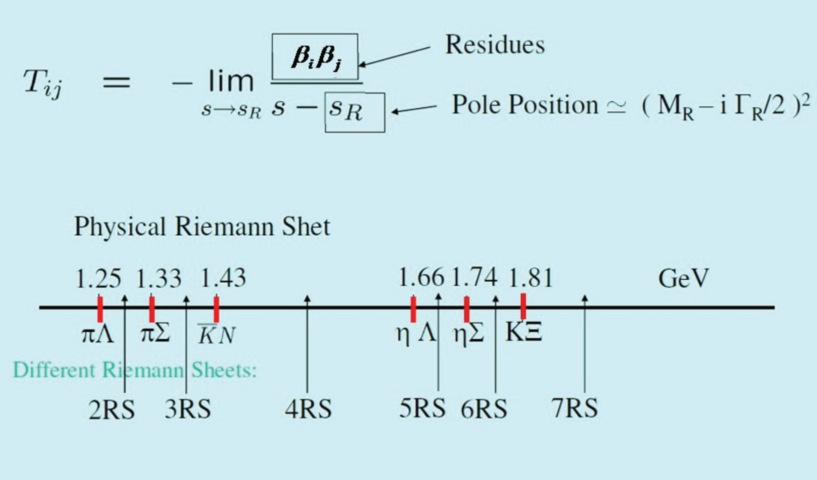


Figure: Real and imaginary parts of $\mathcal{F}(\sqrt{s}) = \frac{T_{K^- p \to K^- p}(\sqrt{s})}{8\pi\sqrt{s}}$.
Fit-I: a common decay constant; **Fit-II:** f_π, f_K, f_η.

$\boxed{\textbf{Important}}$: our results indicate the systematic uncertainty (caused by higher chiral order effects) affecting such extrapolation is larger than the statistical one.

[Guo, Oller, '13PRC]

Baryon resonance poles and their couplings



Baryon resonances: $\Lambda(1670)$ and $\Sigma's$

Pole	$\lvert\beta_{\pi\Lambda}\rvert$	$\lvert\beta_{\pi\Sigma}\rvert_0$	$\lvert\beta_{\pi\Sigma}\rvert_1$	$\lvert\beta_{\pi\Sigma}\rvert_2$	$\lvert\beta_{\bar{K}N}\rvert_0$	$\lvert\beta_{\bar{K}N}\rvert_1$	$\lvert\beta_{\eta\Lambda}\rvert$	$\lvert\beta_{\eta\Sigma}\rvert$	$\lvert\beta_{K\Xi}\rvert_0$	$\lvert\beta_{K\Xi}\rvert_1$
$\Lambda(1670)$										
$1674^{+3}_{-2} - i\,8^{+6}_{-3}$ (4RS)	$0.0^{+0.0}_{-0.0}$	$0.8^{+0.4}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$1.5^{+0.4}_{-0.2}$	$0.0^{+0.0}_{-0.0}$	$1.5^{+0.2}_{-0.2}$	$0.0^{+0.0}_{-0.0}$	$10.8^{+0.2}_{-0.2}$	$0.1^{+0.0}_{-0.0}$
$1674^{+3}_{-3} - i\,11^{+7}_{-3}$ (5RS)	$0.0^{+0.0}_{-0.0}$	$0.9^{+0.4}_{-0.2}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$1.6^{+0.4}_{-0.2}$	$0.0^{+0.0}_{-0.0}$	$1.7^{+0.5}_{-0.3}$	$0.0^{+0.0}_{-0.0}$	$11.1^{+0.3}_{-0.3}$	$0.1^{+0.0}_{-0.0}$
$\Sigma\ I = 1$										
$1646^{+30}_{-127} - i\,160^{+78}_{-36}$ (4RS)	$3.1^{+1.4}_{-0.5}$	$0.0^{+0.0}_{-0.0}$	$3.0^{+0.4}_{-0.5}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$2.9^{+0.4}_{-0.3}$	$0.0^{+0.0}_{-0.0}$	$7.9^{+1.1}_{-1.2}$	$0.0^{+0.0}_{-0.0}$	$6.4^{+1.4}_{-2.2}$
$1878^{+48}_{-59} - i\,169^{+27}_{-34}$ (6RS)	$1.0^{+0.5}_{-0.4}$	$0.0^{+0.0}_{-0.0}$	$5.8^{+0.9}_{-0.6}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$3.7^{+0.4}_{-0.4}$	$0.0^{+0.0}_{-0.0}$	$3.9^{+1.1}_{-1.2}$	$0.1^{+0.0}_{-0.0}$	$16.1^{+2.4}_{-1.6}$

Table: Resonances from Fit I.

Seems not preferred by the CLAS collaboration [Moriya, *et.al.*, PRC'13]

Pole	$\lvert\beta_{\pi\Lambda}\rvert$	$\lvert\beta_{\pi\Sigma}\rvert_0$	$\lvert\beta_{\pi\Sigma}\rvert_1$	$\lvert\beta_{\pi\Sigma}\rvert_2$	$\lvert\beta_{\bar{K}N}\rvert_0$	$\lvert\beta_{\bar{K}N}\rvert_1$	$\lvert\beta_{\eta\Lambda}\rvert$	$\lvert\beta_{\eta\Sigma}\rvert$	$\lvert\beta_{K\Xi}\rvert_0$	$\lvert\beta_{K\Xi}\rvert_1$
$\Lambda(1670)$										
$1676^{+5}_{-3} - i\,7^{+5}_{-3}$ (4RS)	$0.0^{+0.0}_{-0.0}$	$0.9^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$1.5^{+0.4}_{-0.4}$	$0.1^{+0.0}_{-0.0}$	$1.6^{+0.2}_{-0.2}$	$0.1^{+0.0}_{-0.0}$	$10.0^{+0.1}_{-0.1}$	$0.1^{+0.0}_{-0.0}$
$1677^{+5}_{-3} - i\,11^{+5}_{-3}$ (5RS)	$0.0^{+0.0}_{-0.0}$	$0.8^{+0.1}_{-0.1}$	$0.1^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$1.6^{+0.4}_{-0.4}$	$0.1^{+0.0}_{-0.0}$	$1.8^{+0.2}_{-0.2}$	$0.1^{+0.0}_{-0.0}$	$10.5^{+0.2}_{-0.2}$	$0.1^{+0.0}_{-0.0}$
$\Sigma\ I = 1$										
$1376^{+3}_{-3} - i\,33^{+5}_{-5}$ (3RS)	$2.0^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.1^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.1^{+0.0}_{-0.0}$	$2.1^{+0.5}_{-0.4}$	$0.0^{+0.0}_{-0.0}$	$4.0^{+0.5}_{-0.3}$	$0.0^{+0.0}_{-0.0}$	$6.3^{+0.2}_{-0.2}$
$1414^{+2}_{-3} - i\,12^{+1}_{-2}$ (3RS)	$1.9^{+0.1}_{-0.1}$	$0.3^{+0.1}_{-0.1}$	$1.0^{+0.2}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.4^{+0.2}_{-0.1}$	$2.5^{+0.3}_{-0.4}$	$0.2^{+0.1}_{-0.1}$	$3.3^{+0.4}_{-0.4}$	$0.1^{+0.0}_{-0.0}$	$3.3^{+0.3}_{-0.3}$
$1686^{+18}_{-18} - i\,101^{+9}_{-8}$ (5RS)	$0.2^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$3.5^{+0.2}_{-0.2}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$3.5^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$3.9^{+0.3}_{-0.3}$	$0.1^{+0.0}_{-0.0}$	$10.9^{+0.2}_{-0.2}$
$1741^{+12}_{-13} - i\,94^{+3}_{-3}$ (6RS)	$1.1^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$2.3^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$2.8^{+0.1}_{-0.1}$	$0.0^{+0.0}_{-0.0}$	$3.7^{+0.2}_{-0.2}$	$0.1^{+0.0}_{-0.0}$	$7.9^{+0.3}_{-0.2}$

Table: Resonances from Fit II.

Pole	$\lvert\beta_{\pi\Lambda}\rvert$	$\lvert\beta_{\pi\Sigma}\rvert_0$	$\lvert\beta_{\pi\Sigma}\rvert_1$	$\lvert\beta_{\pi\Sigma}\rvert_2$	$\lvert\beta_{\bar{K}N}\rvert_0$	$\lvert\beta_{\bar{K}N}\rvert_1$	$\lvert\beta_{\eta\Lambda}\rvert$	$\lvert\beta_{\eta\Sigma}\rvert$	$\lvert\beta_{K\Xi}\rvert_0$	$\lvert\beta_{K\Xi}\rvert_1$
$\Lambda(1405)$										
$1436^{+14}_{-10} - i\,126^{+24}_{-28}$ (3RS)	$0.0^{+0.0}_{-0.0}$	$8.8^{+0.9}_{-0.4}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$7.7^{+1.3}_{-0.7}$	$0.0^{+0.1}_{-0.0}$	$1.4^{+0.4}_{-0.3}$	$0.0^{+0.1}_{-0.0}$	$2.1^{+0.8}_{-0.7}$	$0.0^{+0.0}_{-0.0}$
$1417^{+4}_{-4} - i\,24^{+7}_{-4}$ (3RS)	$0.1^{+0.0}_{-0.0}$	$5.0^{+1.5}_{-0.8}$	$0.1^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$7.7^{+1.2}_{-0.6}$	$0.1^{+0.0}_{-0.0}$	$1.4^{+0.4}_{-0.3}$	$0.1^{+0.0}_{-0.0}$	$1.5^{+0.7}_{-0.5}$	$0.1^{+0.0}_{-0.0}$

Table: $\Lambda(1405)$ from Fit I.

Pole	$\lvert\beta_{\pi\Lambda}\rvert$	$\lvert\beta_{\pi\Sigma}\rvert_0$	$\lvert\beta_{\pi\Sigma}\rvert_1$	$\lvert\beta_{\pi\Sigma}\rvert_2$	$\lvert\beta_{\bar{K}N}\rvert_0$	$\lvert\beta_{\bar{K}N}\rvert_1$	$\lvert\beta_{\eta\Lambda}\rvert$	$\lvert\beta_{\eta\Sigma}\rvert$	$\lvert\beta_{K\Xi}\rvert_0$	$\lvert\beta_{K\Xi}\rvert_1$
$\Lambda(1405)$										
$1388^{+9}_{-9} - i\,114^{+24}_{-25}$ (3RS)	$0.0^{+0.0}_{-0.0}$	$8.2^{+0.8}_{-0.5}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$6.1^{+1.1}_{-0.6}$	$0.1^{+0.0}_{-0.0}$	$2.2^{+0.6}_{-0.3}$	$0.0^{+0.0}_{-0.0}$	$1.9^{+0.2}_{-0.1}$	$0.1^{+0.0}_{-0.0}$
$1421^{+3}_{-2} - i\,19^{+8}_{-5}$ (3RS)	$0.2^{+0.1}_{-0.1}$	$4.2^{+1.5}_{-0.9}$	$0.2^{+0.0}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$6.2^{+1.2}_{-0.5}$	$0.3^{+0.1}_{-0.1}$	$2.8^{+0.5}_{-0.3}$	$0.4^{+0.2}_{-0.1}$	$0.7^{+0.4}_{-0.3}$	$0.4^{+0.1}_{-0.1}$

Table: $\Lambda(1405)$ from Fit II.

Conclusion: re-confirmation of the double pole structure of $\Lambda(1405)$. The narrower one is robust, while the broader one is kind of model-dependent. Fit II seems preferred.

Further investigation about the two poles of $\Lambda(1405)$:

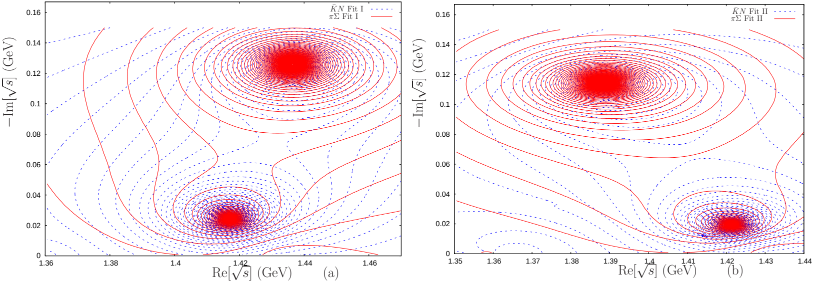


Figure: Contour plot for the modulus of the elastic $I = 0$ $\bar{K}N$ amplitude (blue dashed) and $\pi\Sigma$ amplitude (red solid) S-waves for Fit I [left] and Fit II [right].

[Guo, Oller, '13PRC]

Very preliminary results on $\pi\Sigma$ photoproduction

Our formalism reads [Guo, Oller, in preparation]

$$T_{\gamma p\to K^+\pi^0\Sigma^0} = r_1\,\widetilde{T}^{I=0}|_{\bar{K}N\to\pi\Sigma} + (r_2 + i\bar{r}_2)\,\widetilde{T}^{I=0}|_{\pi\Sigma\to\pi\Sigma}\,,$$

$$\begin{aligned} T_{\gamma p\to K^+\pi^+\Sigma^-} \qquad &= r_1\,\widetilde{T}^{I=0}|_{\bar{K}N\to\pi\Sigma} + (r_2 + i\bar{r}_2)\,\widetilde{T}^{I=0}|_{\pi\Sigma\to\pi\Sigma} \\ &+(r_3 + i\bar{r}_3)\,\widetilde{T}^{I=1}|_{\pi\Sigma\to\pi\Sigma} + (r_4 + i\bar{r}_4)\,\widetilde{T}^{I=1}|_{\bar{K}N\to\pi\Sigma} \\ &+(r_5 + i\bar{r}_5)\,\widetilde{T}^{I=1}|_{\pi\Lambda\to\pi\Sigma}\,, \end{aligned}$$

$$\begin{aligned} T_{\gamma p\to K^+\pi^+\Sigma^-} \qquad &= r_1\,\widetilde{T}^{I=0}|_{\bar{K}N\to\pi\Sigma} + (r_2 + i\bar{r}_2)\,\widetilde{T}^{I=0}|_{\pi\Sigma\to\pi\Sigma} \\ &-(r_3 + i\bar{r}_3)\,\widetilde{T}^{I=1}|_{\pi\Sigma\to\pi\Sigma} - (r_4 + i\bar{r}_4)\,\widetilde{T}^{I=1}|_{\bar{K}N\to\pi\Sigma} \\ &-(r_5 + i\bar{r}_5)\,\widetilde{T}^{I=1}|_{\pi\Lambda\to\pi\Sigma}\,, \end{aligned}$$

with $\widetilde{T} = D^{-1} = [1 + N(W)\cdot g(W^2)]^{-1}\,.$

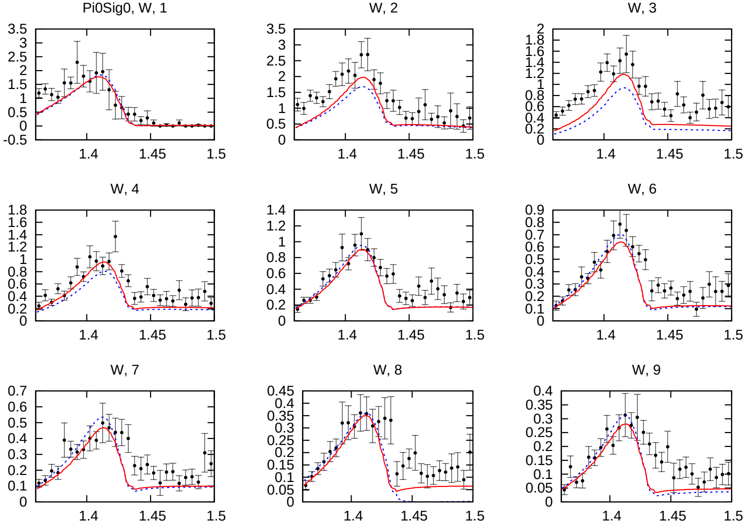


Figure: Preliminary results on $\pi^0\Sigma^0$ photoproduction. Data are taken from [Moriya, *et.al.*, PRC'13]

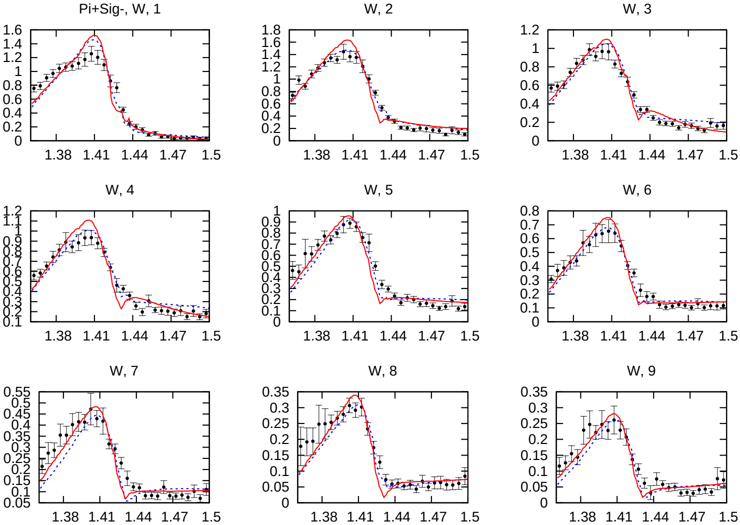


Figure: Preliminary results on $\pi^+\Sigma^-$ photoproduction

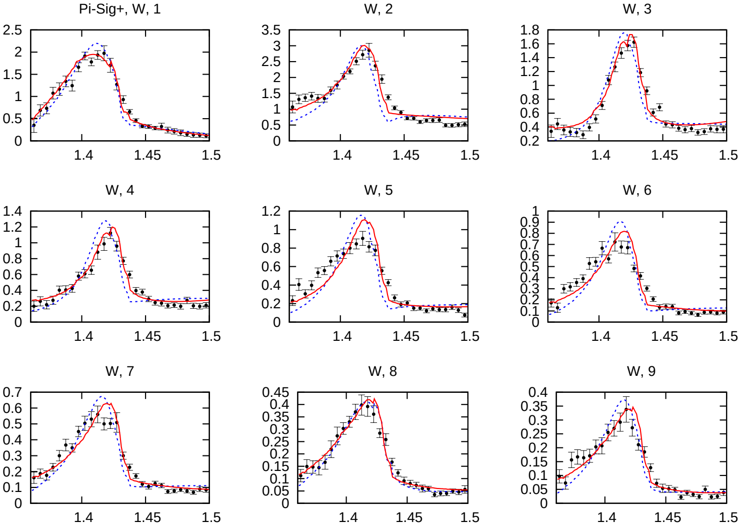


Figure: Preliminary results on $\pi^-\Sigma^+$ photoproduction

Summary and Outlook

- This is a UχPT study of meson-baryon dynamics with strangeness -1 in S-wave up to next-to-leading order.
- Scattering data, including the recent and precise measurements from Crystal Ball Collaboration, and new results on the kanoic hydrogen from SIDDHARTA are considered. They are consistent.
- Two sources of uncertainties are carefully investigated:
  1. A common decay constant *or* distinguishing between f_π, f_K, f_η
  2. Two different ways to define χ^2 in the fit
- Large uncertainties of $K^- p$ scattering amplitudes in subthreshold region are observed. One possible way to improve is to carry out next-to-next-to-leading order study.
- Relevant baryon resonance poles and their couplings are calculated: $\Lambda(1405)$, $\Lambda(1670)$ and various Σ's.
- Photoproduction study is on the way!

谢谢大家!