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Pion-nucleon scattering with decuplet contribution in heavy baryon SU(3) chiral perturbation theory

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Abstract

❖ We calculate the complete T matrices with decuplet contributions for pion-nucleon scattering to order O(ϵ^3) in heavy baryon SU(3) chiral perturbation theory. The baryon mass in the chiral limit M_0 and the low-energy constants are determined by fitting to phase shifts of πN , the experimental octet-baryon masses, and the value of $\sigma_{\pi N}$ simultaneously. By using these constants, we obtain the accurate KN σ terms, $\sigma^{(1)}_{KN}$ = (375.07 ± 33.02) MeV and $\sigma^{(2)}_{KN}$ = (275.32 ± 32.24) MeV. An excellent description of the phase shifts is obtained for all partial waves. We also present results for scattering lengths and scattering volumes. In addition, the convergence of the approach is also discussed.（This paper is currently under review）

Results

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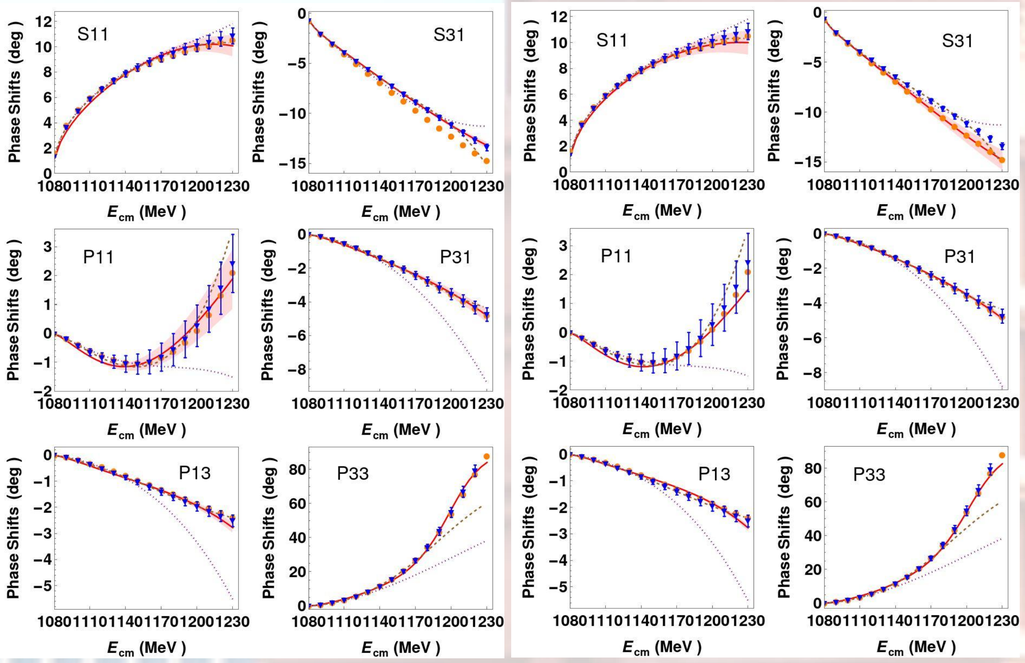

Figs. Results of the πN phase shifts versus the CMS total energy E_{cm} in pion-nucleon(πN) scattering for the fits with the physical baryon masses, the $\sigma_{\pi N}$ and the phase shifts simultaneously. The phase shifts for the fits are in the range of 1125-1220 MeV from the Roy-Steiner equations (Left) and WI08 solutions (Right). The red solid lines refer to our results [O(ϵ^3)] for pion-nucleon phase shifts. The purple dotted lines present the third order [O(p^3)] results without decuplet. The brown dashed lines present the fourth order [O(p^4)] results without decuplet. The blue lower triangles with error bars denote the Roy-Steiner-equation results and the orange circles denote the WI08 solutions from SAID.

	Fit RS	Fit WI08
b_0 (GeV^{-1})	-1.32 ± 0.03	-1.17 ± 0.03
b_D (GeV^{-1})	0.13 ± 0.00	0.13 ± 0.00
b_F (GeV^{-1})	-0.59 ± 0.02	-0.60 ± 0.02
C_1 (GeV^{-1})	-6.95 ± 0.11	-3.97 ± 0.07
C_2 (GeV^{-1})	4.48 ± 0.13	1.75 ± 0.04
C_3 (GeV^{-1})	0.87 ± 0.02	0.09 ± 0.00
H_1 (GeV^{-2})	2.69 ± 0.08	-1.36 ± 0.04
H_2 (GeV^{-2})	-2.77 ± 0.08	-5.43 ± 0.14
H_3 (GeV^{-2})	5.77 ± 0.12	10.38 ± 0.24
H_4 (GeV^{-2})	18.38 ± 0.48	17.53 ± 0.39
C^T (GeV^{-1})	-7.03 ± 0.19	-3.99 ± 0.09
H_1^T (GeV^{-2})	-104.93 ± 2.66	-82.57 ± 2.15
H_2^T (GeV^{-2})	12.41 ± 0.35	-30.13 ± 0.87
M_0 (MeV)	559.91 ± 32.56	714.11 ± 34.60
χ^2/d.o.f.	0.98	3.45

Table 1: Values of the LECs for the fits with the phase shifts from the Roy-Steiner equations (RS) and the WI08 Solution.

		$\mathcal{O}(\epsilon)$	$\mathcal{O}(\epsilon^2)$	$\mathcal{O}(\epsilon^3)$
a^+_{0+} (fm)	RS	0.000	-0.006 ± 0.003	-0.008 ± 0.003
	WI08	0.000	-0.011 ± 0.006	-0.006 ± 0.004
a^-_{0+} (fm)	RS	0.113	0.113 ± 0.000	0.111 ± 0.002
	WI08	0.113	0.113 ± 0.000	0.115 ± 0.003

Table 4: Convergence of the S-wave scattering lengths. O(ϵ^n) means that all terms up-to-and-including order n are given. The errors for our results are obtained by the standard error propagation formula from the fitting constants.

	Input	Fit RS	Fit WI08
M_N (MeV)	938.92 ± 1.29	939.08 ± 8.51	939.06 ± 5.86
M_Σ (MeV)	1191.01 ± 4.86	1190.37 ± 12.90	1191.28 ± 14.19
M_Ξ (MeV)	1318.26 ± 6.30	1322.83 ± 25.05	1323.88 ± 27.22
M_Λ (MeV)	1115.68 ± 5.58	1111.25 ± 13.32	1111.63 ± 13.06
$\sigma_{\pi N}$ (MeV)	59.1 ± 3.5	52.08 ± 2.61	40.30 ± 2.31
$\sigma^{(1)}_{KN}$ (MeV)	—/—	375.07 ± 33.02	226.48 ± 29.93
$\sigma^{(2)}_{KN}$ (MeV)	—/—	275.32 ± 32.24	126.59 ± 35.62

Table 2: Results of the baryon masses and the $\sigma_{\pi N}$ the fits with the physical baryon masses, the $\sigma_{\pi N}$ and the πN phase shifts simultaneously. The two KN σ-terms are predicted by using the resulting constants of the fits.

	Fit RS	Fit WI08	EXP2015	EXP2001
$a^{3/2}_{0+}$ (fm)	-0.119 ± 0.004	-0.121 ± 0.005	-0.122 ± 0.003	-0.121 ± 0.003
$a^{1/2}_{0+}$ (fm)	0.214 ± 0.003	0.223 ± 0.006	0.240 ± 0.003	$0.250^{+0.006}_{-0.004}$
$a^{3/2}_{1+}$ (fm^3)	0.853 ± 0.008	0.871 ± 0.015	—/—	—/—
$a^{1/2}_{1+}$ (fm^3)	-0.115 ± 0.003	-0.104 ± 0.001	—/—	—/—
$a^{3/2}_{1-}$ (fm^3)	-0.156 ± 0.005	-0.150 ± 0.002	—/—	—/—
$a^{1/2}_{1-}$ (fm^3)	-0.268 ± 0.008	-0.260 ± 0.003	—/—	—/—

Table 3: Values of the S- and P -wave scattering lengths and scattering volumes. The errors for our results are obtained by the standard error propagation formula from the fitting constants.

Conclusions

❖ In summary, we calculated the complete T matrices with decuplet contributions for pion-nucleon scattering to order O(ϵ^3) in SU(3) HBχPT. We simultaneously fitted the empirical phase shifts of πN scattering, the experimental octet-baryon masses and the value of $\sigma_{\pi N}$ to determine the M_0 and the LECs. This led to an excellent description of the phase shifts for all partial waves below 1230 MeV total energy in the CMS. The M_0 and LEC uncertainties were analyzed through statistical regression. We obtained the accurate KN σ terms ($\sigma^{(1)}_{KN}$ = 375.07 ± 33.02 MeV, $\sigma^{(2)}_{KN}$ = 275.32 ± 32.24 MeV) using the data from RS equations as inputs. We estimated the scattering lengths and scattering volumes using the constants from the results of fits. The scattering lengths turned out to be in good agreement with those of available experimental data. Finally, we discussed the convergence of the phase shifts and scattering lengths for πN scattering. The results demonstrated a significant improvement in convergence, especially in the P_{33} channel.

❖ Jing Ou-Yang, Bo-Lin Huang. Pion-nucleon scattering with decuplet contribution in heavy baryon SU(3) chiral perturbation theory. arXiv:2409.09388 (under review)

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