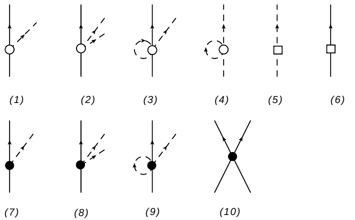
PV potential from chiral EFT

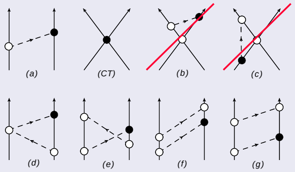
Theoretical studies (at N2LO)

- Kaplan & Savage, NPA **556**, 653 (1993)
- Zhu *et al.*, NPA **748**, 435 (2005)
- Liu, PRC **75**, 065501 (2007); Hyun *et al.*, Mod. Phys. Lett. A **23**, 2293 (2008).
- Viviani *et al.*, 2014, to be completed

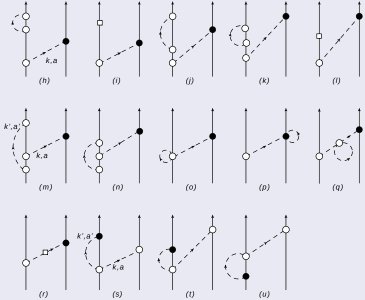
"Vertices"



Processes



plus terms giving a "renormalization of h_π^1"



Expression of the PV potential

$$V_{PV} = \underbrace{V^{(\mathrm{OPE})}}_{\text{order } Q^{-1}} + \underbrace{V^{(\mathrm{TPE})} + V^{(\mathrm{RC})} + V^{(\mathrm{CT})}}_{\text{order } Q^{1}}$$

$$V_{PV}^{(\mathrm{OPE})} = \frac{g_A h_\pi^1}{2\sqrt{2}\, f_\pi} (\vec{\tau}_1 \times \vec{\tau}_2)_z \, \frac{i\,\mathbf{k} \cdot (\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2)}{\omega_k^2}$$

$$V_{PV}^{(\mathrm{TPE})} = -\frac{g_A h_\pi^1}{2\sqrt{2} f_\pi (4\pi f_\pi)^2} (\vec{\tau}_1 \times \vec{\tau}_2)_z \, i\,\mathbf{k} \cdot (\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2)\, L(k) + \cdots$$

$$V_{PV}^{(\mathrm{CT})} = \frac{1}{(4\pi)^2 (f_\pi)^3} \Big[C_1 i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \cdot \mathbf{k} C_2 \vec{\tau}_1 \cdot \vec{\tau}_2 i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \cdot \mathbf{k} + C_3 (\vec{\tau}_1 \times \vec{\tau}_2)_z i(\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2) \cdot \mathbf{k}$$
$$+ C_4 (\tau_{1z} + \tau_{2z}) i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \cdot \mathbf{k} + C_5 (3\vec{\tau}_{1z}\tau_2 - \vec{\tau}_1 \cdot \vec{\tau}_2) i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \cdot \mathbf{k} \Big]$$

- $\mathbf{k} = \mathbf{p}_1' - \mathbf{p}$ ($\mathbf{p}_1$=initial momentum of nucleon 1, etc.); $L(k) = \frac{1}{2}\frac{s}{k} \ln\left(\frac{s+k}{s-k}\right)$, $s = \sqrt{k^2 + 4\, m_\pi^2}$, $\omega = \sqrt{k^2 + m_\pi^2}$
- TPE: same expression as Zhu *et al.* & Hyun *et al.*
- Six parameters (LEC's): h_π^1 & $C_{1,\ldots,5}$
- The potential is multiplied by a cutoff function $\exp[-(k/\Lambda)^4]$
- Chosen values: $\Lambda = 500$ & 600 MeV

The $^3\mathrm{He}(\vec{n},p)^3\mathrm{H}$ longitudinal asymmetry

Contact terms $\rightarrow$ same structure as the part of the DDH pot. coming from ρ- and ω-exchanges
it is possible to estimate $C_{1,\ldots,5}$ from the values of the DDH coupling constants
in units of 10^{-7}:

$$C_1^{(\mathrm{DDH})} \approx 1\ , \quad C_2^{(\mathrm{DDH})} \approx +30\ , \quad C_3^{(\mathrm{DDH})} \approx -2\ , \quad C_4^{(\mathrm{DDH})} \approx 0\ , \quad C_5^{(\mathrm{DDH})} \approx +7$$

$$A_z = \left(a_0 h_\pi^1 + a_1 C_1 + a_2 C_2 + a_3 C_3 + a_4 C_4 + a_5 C_5\right) \cos\theta$$

$p - {}^3\mathrm{H}$ and $n - {}^3\mathrm{He}$: solution of the 4-body scattering problem with the HH method
[Viviani *et al.*, PRC bf 82, 044001 (2010)]
Strong interaction also derived from chiral EFT: N3LO NN potential
[Entem and Machleidt, PRC **68**, 041001 (2003)]
+ N2LO 3N interaction [Epelbaum *et al.*, PRC **66**, 064001 (2002)]

PRELIMINARY

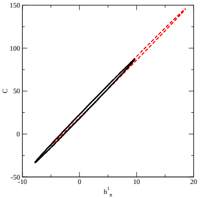
Λ [MeV]	a_0	a_1	a_2	a_3	a_4	a_5
500	-0.1444	0.0061	0.0226	-0.0199	-0.0174	-0.0005
600	-0.1293	0.0081	0.0320	-0.0161	-0.0156	-0.0001

From the experimental $p - \vec{p}$ longit. asymm.

$$\overline{A}_z^{pp}(E) = a_0^{(pp)}(E)\, h_\pi^1 + a_1^{(pp)}(E)\, C$$

$$C = C_1 + C_2 + 2\,(C_4 + C_5)$$

χ^2 analysis from the fit of the three expt. data



Values assumed for h_π^1

- $h_\pi^1 = 1 \times 10^{-7}$ (lattice estimate – [Wasem PRC **85**, 022501 (2012)])
- $h_\pi^1 = 4.56 \times 10^{-7}$ (DDH "best value");
- $h_\pi^1 = 11.4 \times 10^{-7}$ (maximum value allowed in the DDH "reasonable range").

We assume $C_1 = 1$, $C_3 = -1$, $C_4 = 1$, C_5 chosen as specified below, and C_2 fixed to give C

	$\Lambda = 500$ MeV			$\Lambda = 600$ MeV		
SET	I	II	III	I	II	III
h_π^1	1.0	4.56	11.4	1.0	4.56	11.4
C_5	5.0	10.0	20.0	5.0	10.0	20.0
C_2	13.7	28.5	56.2	14.6	28.4	54.2

Results

Cumulative contributions to a_z in units of 10^{-7} ($A_z = a_z \cos\theta$) (PRELIMINARY) for the sets I, II, and III of the LEC's specified in the previous table

a_z	$\Lambda = 500$ MeV			$\Lambda = 600$ MeV		
SET	I	II	III	I	II	III
OPE	-0.118	-0.537	-1.34	-0.099	-0.453	-1.13
TPE	-0.147	-0.669	-1.67	-0.131	-0.597	-1.49
RC	-0.144	-0.658	-1.65	-0.129	-0.589	-1.47
CT	0.171	-0.012	-0.38	0.346	0.326	0.27

- Cancellation between the contributions coming from h_π^1 and C_2
- Mild dependence on Λ, enhanced by the cancellations