Formalism of YN at NLO

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Introduction/Motivation

- Goal: determine YN and YY interactions
  $\rightarrow$ empirical constraints from YN scattering and Λ hypernuclei (past and future experiments)
  $\rightarrow$ strange baryons in nuclear matter
  (• hypernuclei • exotic neutron star matter)
- Extend SU(2) BχPT (accurate description of nuclear interactions: Weinberg, Kaiser, Epelbaum, Machleidt, ...) to include strangeness
  $\Rightarrow$ SU(3) BχPT
- YN and YY interactions in LO SU(3) BχPT by Jülich group
  [Polinder, Haidenbauer, Meißner, Nucl.Phys. A779, 2006]
  (alternative: phenomenological one-boson-exchange models)

New result

systematic NLO analysis of baryon-baryon interactions using SU(3) BχPT

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Construction of chiral Lagrangian

- BχPT: EFT with mesons and baryons as degrees of freedom
- consistent with symmetries of QCD Lagrangian (C,P,T, Lorentz invariance) and chiral symmetry $\mathrm{SU(3)_L} \times \mathrm{SU(3)_R}$ and its symmetry breaking
- for construction of Lagrangian: include external fields (v^μ, a^μ, s, p) and promte chiral symmetry to a local symmetry
- non-linear realization of pseudoscalar goldstone bosons

$$\phi = \begin{pmatrix} \pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}\pi^+ & \sqrt{2}K^+ \\ \sqrt{2}\pi^- & -\pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}K^0 \\ \sqrt{2}K^- & \sqrt{2}\bar{K}^0 & -\frac{2\eta}{\sqrt{3}} \end{pmatrix}$$

with $U(x) = \exp\left(\mathrm{i}\frac{\phi(x)}{f_0}\right)$ and $U \to RUL^\dagger$

Construction of chiral Lagrangian

- non-linear realization of octet baryons

$$B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

  with chiral transformation behavior $B \to KBK^\dagger$
  ($K = K\,(L, R, U)$, SU(3) valued function)

- choose building blocks $u_\mu, \chi_+, \chi_-, f^+_{\mu\nu}, f^-_{\mu\nu}$,
  consisting of ϕ, B and external fields

- all building blocks transform as $X \to KXK^\dagger$;
  covariant derivative $D_\mu X = \partial_\mu X + [\Gamma_\mu, X]$ as $D_\mu X \to K(D_\mu X)K^\dagger$

- for NLO BB interaction:
  $f^\pm_{\mu\nu} = 0,\ \chi_- = 0,\ \chi_+ = 2B_0\,\mathrm{diag}(m_u, m_d, m_s)$

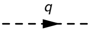
Chiral meson Lagrangian

Meson Lagrangian (in isospin limit $m_u = m_d \neq m_s$)

$$\mathscr{L}_\phi^{(2)} = \frac{f_0^2}{4} \operatorname{tr}\left(\partial_\mu U \partial^\mu U^\dagger\right) + \frac{1}{2} B_0 f_0^2 \operatorname{tr}\left(M U^\dagger + U M\right)$$

- $M = \operatorname{diag}\left(m_u, m_d, m_s\right)\,, \quad U(x) = \exp\left(\mathrm{i}\frac{\phi(x)}{f_0}\right)$

$$\phi = \begin{pmatrix} \pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}\pi^+ & \sqrt{2}K^+ \\ \sqrt{2}\pi^- & -\pi^0 + \frac{\eta}{\sqrt{3}} & \sqrt{2}K^0 \\ \sqrt{2}K^- & \sqrt{2}\bar{K}^0 & -\frac{2\eta}{\sqrt{3}} \end{pmatrix} \quad \text{Meson octet}$$

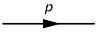
- gives meson propagator: 

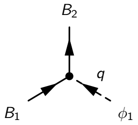
- Gell-Mann–Okubo relation: $4m_K^2 = m_\pi^2 + 3m_\eta^2$

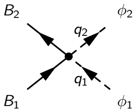
Chiral meson-baryon Lagrangian

Meson-baryon interaction

$$\mathscr{L}^{(1)}_{\mathrm{MB}} = \mathrm{tr}\left(\bar{B}\left(\mathrm{i}\not{D} - M_0\right)B - \frac{D}{2}\bar{B}\gamma^\mu\gamma_5\{u_\mu, B\} - \frac{F}{2}\bar{B}\gamma^\mu\gamma_5\left[u_\mu, B\right]\right)$$

- $B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$ Baryon octet
- D, F: axial vector couplings, $D + F = g_{\mathrm{A}}$
- gives baryon propagator: 

three-vertex: 

and four-vertex: 

Chiral meson-baryon Lagrangian

Nonrelativistic decuplet interaction Lagrangian

$$\mathscr{L}^{(1)}_{\mathrm{MBD}} = \frac{C}{f_0} \sum_{a,b,c,d,e=1}^{3} \epsilon_{abc} \left[\bar{T}_{ade} \vec{S}^{\,\dagger} \cdot \left(\vec{\nabla} \phi_{db} \right) B_{ec} + \text{h.c.} \right]$$

[Sasaki, Oset, Vacas, Phys.Rev. C74, 2006]

- total symmetric 3 index tensor T for decuplet baryon fields

  $T^{111} = \Delta^{++}$ $\quad T^{112} = \frac{\Delta^{+}}{\sqrt{3}}$ $\quad T^{122} = \frac{\Delta^{0}}{\sqrt{3}}$ $\quad T^{222} = \Delta^{-}$

  $T^{113} = \frac{\Sigma^{*+}}{\sqrt{3}}$ $\quad T^{123} = \frac{\Sigma^{*0}}{\sqrt{6}}$ $\quad T^{223} = \frac{\Sigma^{*-}}{\sqrt{3}}$

  $T^{133} = \frac{\Xi^{*0}}{\sqrt{3}}$ $\quad T^{233} = \frac{\Xi^{*-}}{\sqrt{3}}$

  $T^{223} = \Omega^{-}$

- S_i: spin transition matrix (2x4)

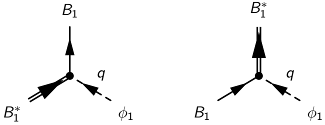
Chiral meson-baryon Lagrangian

Nonrelativistic decuplet interaction Lagrangian

$$\mathscr{L}^{(1)}_{\mathrm{MBD}} = \frac{C}{f_0} \sum_{a,b,c,d,e=1}^{3} \epsilon_{abc} \left[\bar{T}_{ade} \vec{S}^{\,\dagger} \cdot \left(\vec{\nabla} \phi_{db} \right) B_{ec} + \text{h.c.} \right]$$

[Sasaki, Oset, Vacas, Phys.Rev. C74, 2006]

- C from the decay width $\Gamma(\Delta \to \pi N) \approx 115\ \mathrm{MeV}$
  $C = \frac{3}{4} g_A \approx 1$ [cf. Kaiser, Gerstendörfer, Weise, Nucl.Phys. A637, 1998]
- gives three-vertex:



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Power counting scheme

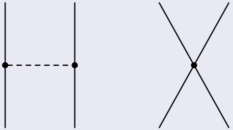
- additional *large* scale M_0; non-vanishing in chiral limit
- treat baryons non-relativistically $\Rightarrow$ expansion in $1/M_0$
- two-particle reducible Feynman diagrams destroy power counting
  $\Rightarrow$ define *potential* as *2P-irreducible* part of T-matrix
- reducible parts generated by *Lippmann-Schwinger equation*
- Weinberg power counting

chiral dimension $\quad \nu = 2L + \sum_i \Delta_i \, , \quad \Delta_i = d_i + \frac{1}{2} b_i - 2$

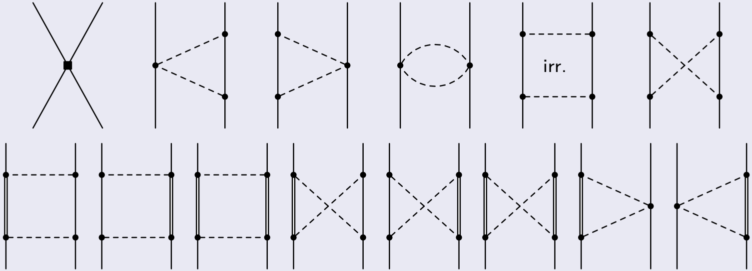
L: # meson loops
Δ_i: vertex i
d_i: # derivatives or meson masses of vertex i
b_i: # internal baryon lines of vertex i

Power counting for baryon-baryon potential

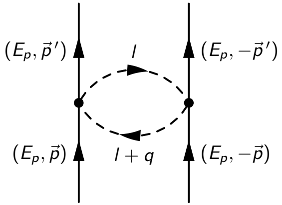
Leading order



Next-to-leading order



Example: Football Diagram



- m_1, m_2 masses of exchanged mesons
- $q = |\vec{q}|$ momentum transfer, $(\vec{q} = \vec{p}\,' - \vec{p})$
- $R = \frac{2}{d-4} + \gamma - 1 - \ln(4\pi)$
- scale λ introduced in dim. regularization

$$V_C(q) = -\frac{N}{3072\pi^2 f_0^4}\left[\frac{1}{2}\left(3\left(m_1^2+m_2^2\right)+q^2\right)R - \frac{\left(m_1^2-m_2^2\right)^2}{2q^2} - 2\left(m_1^2+m_2^2\right) - \frac{5}{6}q^2 - \frac{m_1^2-m_2^2}{2q^4} + w^2(q)L(q) + \left(\left(m_1^2-m_2^2\right)^2 + 3\left(m_1^2+m_2^2\right)q^2\right)\ln\frac{m_1}{m_2} + \left(3\left(m_1^2+m_2^2\right)+q^2\right)\ln\frac{\sqrt{m_1 m_2}}{\lambda}\right]$$

$$w(q) = \frac{1}{q}\sqrt{\left(q^2+(m_1+m_2)^2\right)\left(q^2+(m_1-m_2)^2\right)}, \quad L(q) = \frac{w(q)}{2q}\ln\frac{\left(qw(q)+q^2\right)^2 - \left(m_1^2-m_2^2\right)^2}{4m_1 m_2 q^2}$$

Baryon-baryon potentials

- strong interaction conserves isospin I and strangeness S (and is independent of I_3)
- the Lippmann-Schwinger equation couples only states with the same values of these quantum numbers

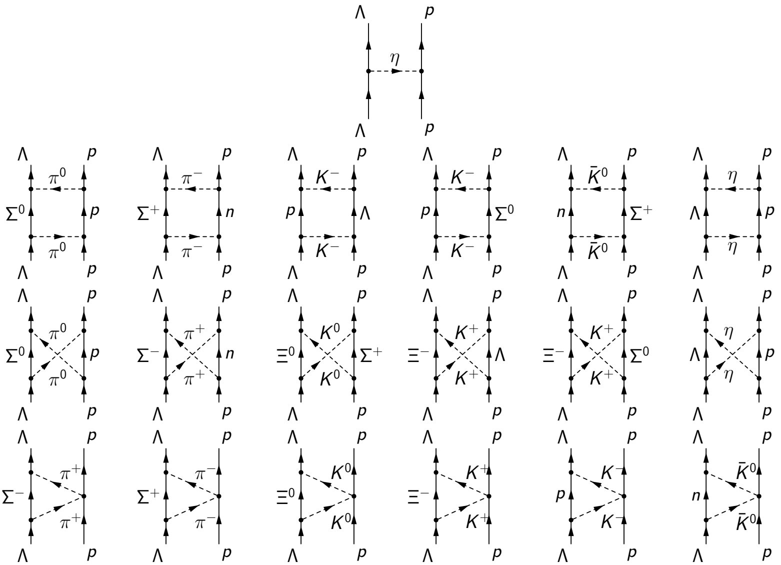
$$V = \begin{pmatrix} V_{(\Lambda N)^{1/2} \to (\Lambda N)^{1/2}} & V_{(\Lambda N)^{1/2} \to (\Sigma N)^{1/2}} \\ V_{(\Sigma N)^{1/2} \to (\Lambda N)^{1/2}} & V_{(\Sigma N)^{1/2} \to (\Sigma N)^{1/2}} \end{pmatrix}, \qquad V = V_{(\Sigma N)^{3/2} \to (\Sigma N)^{3/2}}$$

$$V = \begin{pmatrix} V_{(\Lambda\Lambda)^0 \to (\Lambda\Lambda)^0} & V_{(\Lambda\Lambda)^0 \to (\Sigma\Sigma)^0} & V_{(\Lambda\Lambda)^0 \to (N\Xi)^0} \\ V_{(\Sigma\Sigma)^0 \to (\Lambda\Lambda)^0} & V_{(\Sigma\Sigma)^0 \to (\Sigma\Sigma)^0} & V_{(\Sigma\Sigma)^0 \to (N\Xi)^0} \\ V_{(N\Xi)^0 \to (\Lambda\Lambda)^0} & V_{(N\Xi)^0 \to (\Sigma\Sigma)^0} & V_{(N\Xi)^0 \to (N\Xi)^0} \end{pmatrix}$$

Important result

Transition potentials as large as diagonal (elastic) potentials

Diagrams for $\Lambda p \to \Lambda p$ with octet baryons



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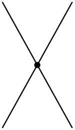
Chirally symmetric contact terms

- LO+NLO contact terms of NN interaction [Epelbaum, 2000] generalized by SU(3) flavor symmetry
$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{10} \oplus \mathbf{10}^* \oplus \mathbf{8_s} \oplus \mathbf{8_a} \oplus \mathbf{1}$$
- flavor symmetric $\mathbf{27}, \mathbf{8_s}, \mathbf{1} \Rightarrow$ for space-spin antisymmetric states
$$V^i(^1\mathrm{S}_0) = \tilde{C}^i_{^1\mathrm{S}_0} + C^i_{^1\mathrm{S}_0}(p^2 + p'^2)$$
$$V^i(^3\mathrm{P}_0) = C^i_{^3\mathrm{P}_0}(pp')$$
$$V^i(^3\mathrm{P}_1) = C^i_{^3\mathrm{P}_1}(pp')$$
$$V^i(^3\mathrm{P}_2) = C^i_{^3\mathrm{P}_2}(pp')$$
- flavor antisymmetric $\mathbf{10}, \mathbf{10}^*, \mathbf{8_a} \Rightarrow$ for space-spin symmetric states
$$V^i(^3\mathrm{S}_1) = \tilde{C}^i_{^3\mathrm{S}_1} + C^i_{^3\mathrm{S}_1}(p^2 + p'^2)$$
$$V^i(^1\mathrm{P}_1) = C^i_{^1\mathrm{P}_1}(pp')$$
$$V^i(^3\mathrm{D}_1 - {}^3\mathrm{S}_1) = C^i_{^3\mathrm{D}_1 - {}^3\mathrm{S}_1} p'^2$$
$$V^i(^3\mathrm{S}_1 - {}^3\mathrm{D}_1) = C^i_{^3\mathrm{D}_1 - {}^3\mathrm{S}_1} p^2$$
- does not include SU(3) breaking effects

	Channel	Isospin	C_{1S0}	Isospin	C_{3S1}
$S=0$	$NN\to NN$	1	C^{27}	0	C^{10^*}
$S=-1$	$\Lambda N\to\Lambda N$	$\frac{1}{2}$	$\frac{1}{10}\left(9C^{27}+C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(C^{8_a}+C^{10^*}\right)$
	$\Lambda N\to\Sigma N$	$\frac{1}{2}$	$\frac{3}{10}\left(-C^{27}+C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(-C^{8_a}+C^{10^*}\right)$
	$\Sigma N\to\Sigma N$	$\frac{1}{2}$	$\frac{1}{10}\left(C^{27}+9C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(C^{8_a}+C^{10^*}\right)$
	$\Sigma N\to\Sigma N$	$\frac{3}{2}$	C^{27}	$\frac{3}{2}$	C^{10}
$S=-2$	$\Lambda\Lambda\to\Lambda\Lambda$	0	$\frac{1}{40}\left(27C^{27}+8C^{8_s}+5C^{1}\right)$		
	$\Lambda\Lambda\to\Xi N$	0	$\frac{-1}{40}\left(18C^{27}-8C^{8_s}-10\,C^{1}\right)$		
	$\Lambda\Lambda\to\Sigma\Sigma$	0	$\frac{\sqrt{3}}{40}\left(-3C^{27}+8C^{8_s}-5C^{1}\right)$		
	$\Xi N\to\Xi N$	0	$\frac{1}{40}\left(12C^{27}+8C^{8_s}+20\,C^{1}\right)$	0	C^{8_a}
	$\Xi N\to\Sigma\Sigma$	0	$\frac{\sqrt{3}}{40}\left(2C^{27}+8C^{8_s}-10\,C^{1}\right)$	1	$\frac{\sqrt{2}}{6}\left(C^{10}+C^{10^*}-2C^{8_a}\right)$
	$\Sigma\Sigma\to\Sigma\Sigma$	0	$\frac{1}{40}\left(C^{27}+24C^{8_s}+15C^{1}\right)$	1	$\frac{1}{6}\left(C^{10}+C^{10^*}+4C^{8_a}\right)$
	$\Xi N\to\Xi N$	1	$\frac{1}{5}\left(2C^{27}+3C^{8_s}\right)$	1	$\frac{1}{3}\left(C^{10}+C^{10^*}+C^{8_a}\right)$
	$\Xi N\to\Sigma\Lambda$	1	$\frac{\sqrt{6}}{5}\left(C^{27}-C^{8_s}\right)$	1	$\frac{\sqrt{6}}{6}\left(C^{10}-C^{10^*}\right)$
	$\Sigma\Lambda\to\Sigma\Lambda$	1	$\frac{1}{5}\left(3C^{27}+2C^{8_s}\right)$	1	$\frac{1}{2}\left(C^{10}+C^{10^*}\right)$
	$\Sigma\Lambda\to\Sigma\Sigma$			1	$\frac{\sqrt{3}}{6}\left(C^{10}-C^{10^*}\right)$
	$\Sigma\Sigma\to\Sigma\Sigma$	2	C^{27}		
$S=-3$	$\Xi\Lambda\to\Xi\Lambda$	$\frac{1}{2}$	$\frac{1}{10}\left(9C^{27}+C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(C^{8_a}+C^{10}\right)$
	$\Xi\Lambda\to\Xi\Sigma$	$\frac{1}{2}$	$\frac{3}{10}\left(-C^{27}+C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(-C^{8_a}+C^{10}\right)$
	$\Xi\Sigma\to\Xi\Sigma$	$\frac{1}{2}$	$\frac{1}{10}\left(C^{27}+9C^{8_s}\right)$	$\frac{1}{2}$	$\frac{1}{2}\left(C^{8_a}+C^{10}\right)$
	$\Xi\Sigma\to\Xi\Sigma$	$\frac{3}{2}$	C^{27}	$\frac{3}{2}$	C^{10^*}
$S=-4$	$\Xi\Xi\to\Xi\Xi$	1	C^{27}	0	C^{10}

[Haidenbauer, Meißner, Phys.Lett.B653, 2009]

Chiral symmetry breaking in contact terms



$$\mathcal{L}_1 = C_1^i \langle \bar{B}_1 \Gamma^i B_1 \bar{B}_2 \Gamma^i B_2 \rangle$$
$$\mathcal{L}_2 = C_2^i \langle \bar{B}_1 \bar{B}_2 \Gamma^i B_1 \Gamma^i B_2 \rangle$$
$$\mathcal{L}_3 = C_3^i \langle \bar{B}_1 \Gamma^i B_1 \rangle \langle \bar{B}_2 \Gamma^i B_2 \rangle$$

$$\Gamma^i \in \{\mathbb{1}, \gamma_\mu, \gamma_5, \gamma_5\gamma_\mu, \sigma_{\mu\nu}\}$$

$$\bar{u}_i = \bar{u}_i(M_i, p'), \quad u_j = u_j(M_j, p), \quad M_i = M_0 + \Delta_i, \quad M_j = M_0 + \Delta_j,$$

$$\bar{u}_i \gamma^0 \gamma_5 u_j \approx \frac{\vec{\sigma} \cdot (\vec{p} + \vec{p}\,')}{2M_0} - \frac{\Delta_j \vec{\sigma} \cdot \vec{p} + \Delta_i \vec{\sigma} \cdot \vec{p}\,'}{2M_0^2}$$

$$\bar{u}_i \vec{\gamma} \gamma_5 u_j \approx \vec{\sigma} + \frac{p^2 + p'^2}{8M_0^2} \vec{\sigma} + \frac{\vec{\sigma} \cdot \vec{p}\,' \; \vec{\sigma} \; \vec{\sigma} \cdot \vec{p}}{4M_0^2}$$

$$\bar{u}_i \sigma^{0l} u_j \approx \mathrm{i} \frac{(p^l - p'^l) + \mathrm{i}\epsilon^{lmn}(p^m + p'^m)\sigma^n}{2M_0} - \mathrm{i} \frac{\Delta_j \sigma^l \, \vec{\sigma} \cdot \vec{p} - \Delta_i \vec{\sigma} \cdot \vec{p}\,' \sigma^l}{2M_0^2}$$

$$\vdots$$

$\Rightarrow$ lead to explicit chiral symmetry breaking in relativistic corrections to LO contact terms due to different baryon masses

Chiral symmetry breaking in contact terms

$$\mathcal{L}_1 = C_1^i \langle \bar{B}_1 \chi \Gamma^i B_1 \bar{B}_2 \Gamma^i B_2 \rangle$$

$$\mathcal{L}_2 = C_2^i \langle \bar{B}_1 \Gamma^i B_1 \chi \bar{B}_2 \Gamma^i B_2 \rangle$$

$$\mathcal{L}_3 = C_3^i \langle \bar{B}_1 \chi \bar{B}_2 \Gamma^i B_1 \Gamma^i B_2 \rangle + \langle \bar{B}_1 \bar{B}_2 \Gamma^i B_1 \chi \Gamma^i B_2 \rangle$$

$$\mathcal{L}_4 = C_4^i \langle \bar{B}_1 \bar{B}_2 \chi \Gamma^i B_1 \Gamma^i B_2 \rangle$$

$$\mathcal{L}_5 = C_5^i \langle \bar{B}_1 \bar{B}_2 \Gamma^i B_1 \Gamma^i B_2 \chi \rangle$$

$$\mathcal{L}_6 = C_6^i \langle \bar{B}_1 \Gamma^i B_1 \chi \rangle \langle \bar{B}_2 \Gamma^i B_2 \rangle$$

$$\chi = 2B_0 \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix} \approx \begin{pmatrix} m_\pi^2 & 0 & 0 \\ 0 & m_\pi^2 & 0 \\ 0 & 0 & 2m_K^2 - m_\pi^2 \end{pmatrix}$$

$\Rightarrow$ lead to explicit chiral symmetry breaking linear in the quark masses

complete $\mathcal{O}(q^2)$ contact Lagrangian including external fields $\chi_\pm, f_{\mu\nu}^\pm, u_\mu$ constructed

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Summary

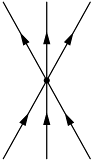
- NLO analysis of one- and two-*meson exchange* contributions to (irreducible) BB potentials using SU(3) BχPT
- many different Feynman diagrams contribute;
  can be reduced to few master loop integrals
- relativistic Lagrangians for *contact terms* constructed
- chiral symmetry breaking in two-meson exchange due to different meson masses
- chiral symmetry breaking in relativistic corrections to LO contact terms due to different baryon masses
- chiral symmetry breaking in contact terms due to quark mass matrix in external field χ

Outlook

Three baryon contact terms

$$\langle \bar{B}\bar{B}\bar{B}BBB \rangle$$
$$\langle \bar{B}\bar{B}B\bar{B}BB \rangle$$
$$\langle \bar{B}\bar{B}BB\bar{B}B \rangle$$
$$\langle \bar{B}B\bar{B}B\bar{B}B \rangle$$
$$\langle \bar{B}\bar{B}\bar{B}B \rangle\langle BB \rangle \pm \langle \bar{B}\bar{B} \rangle\langle \bar{B}BBB \rangle$$
$$\langle \bar{B}\bar{B}BB \rangle\langle \bar{B}B \rangle$$
$$\langle \bar{B}B\bar{B}B \rangle\langle \bar{B}B \rangle$$
$$\langle \bar{B}\bar{B}\bar{B} \rangle\langle BBB \rangle$$
$$\langle \bar{B}\bar{B}B \rangle\langle \bar{B}BB \rangle$$
$$\langle \bar{B}\bar{B} \rangle\langle \bar{B}B \rangle\langle BB \rangle$$
$$\langle \bar{B}B \rangle\langle \bar{B}B \rangle\langle \bar{B}B \rangle$$

Γ_1	Γ_2	Γ_3
$\mathbb{1}$	$\mathbb{1}$	$\mathbb{1}$
$\mathbb{1}$	$\sigma^{\mu\nu}$	$\sigma_{\mu\nu}$
$\mathbb{1}$	$\gamma_5\gamma^\mu$	$\gamma_5\gamma_\mu$
$\sigma^{\mu\nu}$	$\gamma_5\gamma_\mu$	$\gamma_5\gamma_\nu$
$\sigma^{\mu}{}_{\nu}$	$\sigma_{\mu\rho}$	$\sigma^{\nu\rho}$



leads after non-relativistic expansion to potentials of the form

$$\mathbb{1}\,, \quad \vec{\sigma}_1 \cdot \vec{\sigma}_2\,, \quad \vec{\sigma}_1 \cdot \vec{\sigma}_3\,, \quad \vec{\sigma}_2 \cdot \vec{\sigma}_3\,, \quad \vec{\sigma}_1 \times \vec{\sigma}_2 \cdot \vec{\sigma}_3$$

Outlook

Three baryon contact terms

consistency check with tensor products in

- flavor space: $\mathbf{8} \otimes \mathbf{8} \otimes \mathbf{8} = \mathbf{64} \oplus (\mathbf{35} \oplus \overline{\mathbf{35}})_2 \oplus \mathbf{27}_6 \oplus (\mathbf{10} \oplus \overline{\mathbf{10}})_4 \oplus \mathbf{8}_8 \oplus \mathbf{1}_2$
- spin space: $\mathbf{2} \otimes \mathbf{2} \otimes \mathbf{2} = \mathbf{4} \oplus \mathbf{2}_2$

subscript: multiplicity of irreducible repesentation

Three baryon diagrams with intermediate decuplet baryons