האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

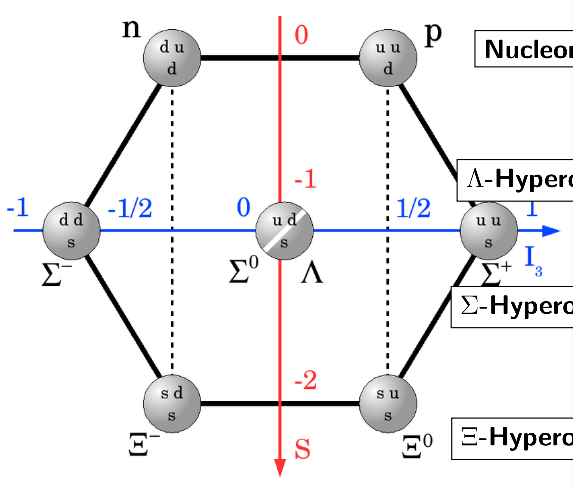
Studies in Baryonic EFT aka $\not\pi$EFT

Nir Barnea

THE NUCLEAR INTERACTION: POST-MODERN DEVELOPMENTS
ECT*, August 2024

Overview

- Baryonic EFT
- Light Nuclei
- Lattice QCD
- Magnetic Moments etc.
- Light Hypernuclei @LO
- Charge symmetry breaking
- Conclusions



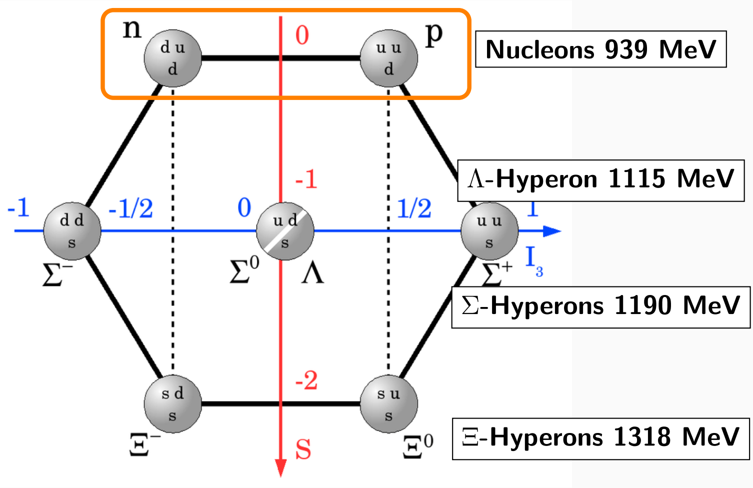
Nucleons 939 MeV

Λ-Hyperon 1115 MeV

Σ-Hyperons 1190 MeV

Ξ-Hyperons 1318 MeV

Introduction - the baryon octet



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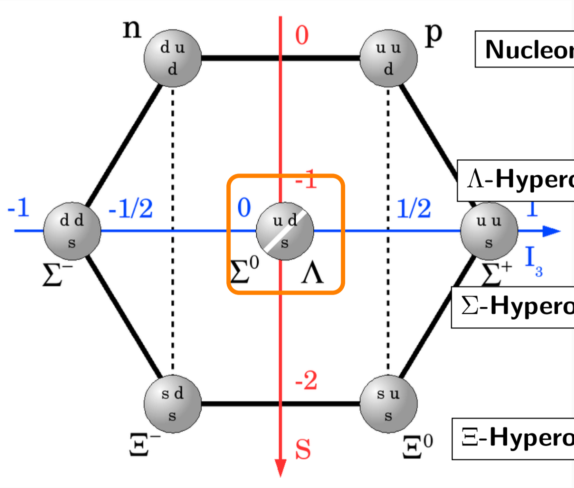

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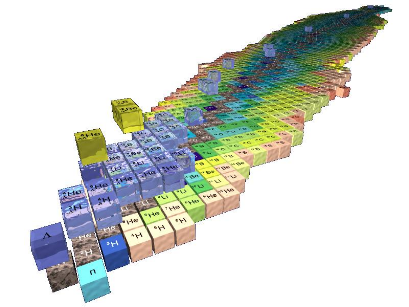


Nuclei & Hypernuclei

≈3300 nuclear isotopes

≈40 single Lambda hypernuclei

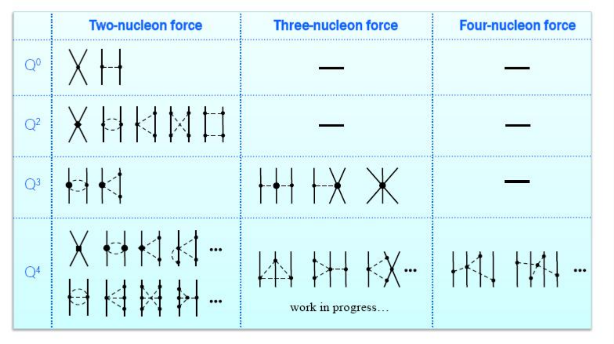
3 double Lambda hypernuclei

Baryonic EFT

	2-body	3-body	4-body	5-body
LO	C_1	D_1	–	–
NLO	C_2	–	E_2	–
N^2LO	C_3	D_3	?	?

Weinberg, van Kolck, Epelbaum, Machleidt, Meissner, ...

$$\boxed{\mathcal{L}_{QCD}(q,G) \longrightarrow \mathcal{L}_{\chi EFT}(B,\pi,K)}$$



$$V_{LO} = \underbrace{V_\pi(\boldsymbol{r})}_{1-\text{pion exchange}} + \underbrace{(c_S + c_T \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)\delta(\boldsymbol{r})}_{\delta \text{ interactions}}$$

The Nuclear Interaction - χEFT

Weinberg, van Kolck, Epelbaum, Machleidt, Meissner, ...

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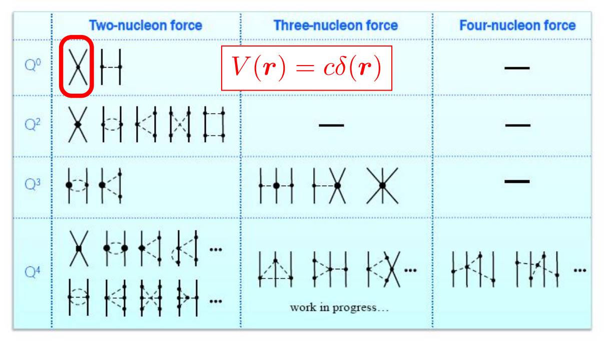

$$V(\boldsymbol{r}) = c\delta(\boldsymbol{r})$$

$$V_{LO} = \underbrace{V_\pi(\boldsymbol{r})}_{1-\text{pion exchange}} + \underbrace{(c_S + c_T \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)\delta(\boldsymbol{r})}_{\delta \text{ interactions}}$$

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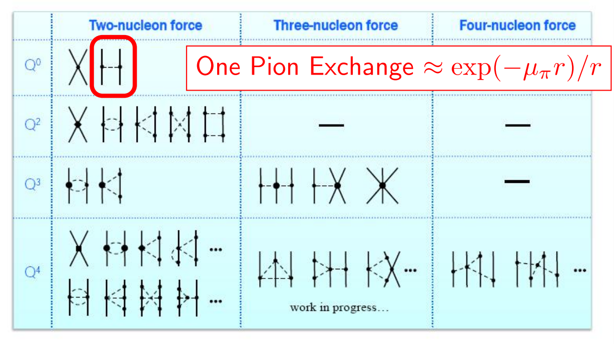
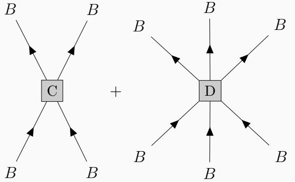


One Pion Exchange $\approx \exp(-\mu_\pi r)/r$

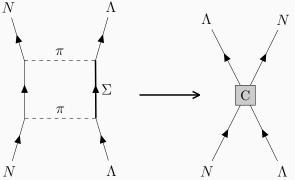
$$V_{LO} = \underbrace{V_\pi(\boldsymbol{r})}_{1-\text{pion exchange}} + \underbrace{(c_S + c_T \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)\delta(\boldsymbol{r})}_{\delta \text{ interactions}}$$

- $B = n, p, \Lambda, \ldots$ are the only DOF.

$$\mathcal{L}_{QCD}(q,G) \longrightarrow \mathcal{L}_{\chi EFT}(B,\pi,K) \longrightarrow \mathcal{L}(B)$$

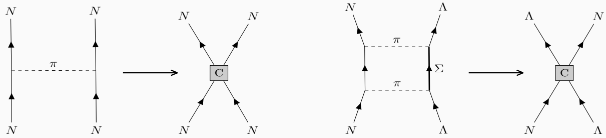


- $\mathcal{L}$ is expanded in powers of Q/M_h.
- Include contact terms and derivatives.
- Not too many parameters



$$\mathcal{L} = B^\dagger\left(i\partial_0 + \frac{\nabla^2}{2M}\right)B + \mathcal{L}_{2B} + \mathcal{L}_{3B} + \ldots$$

- The simplest possible EFT.



The small (?) parameter

Nuclei The pion mass is our breaking scale M_h

$$\left(\frac{Q}{M_h}\right) = \frac{\sqrt{2B_N M_N}}{m_\pi} \approx 0.5 - 0.8$$

Seems to work better in practice as $\Delta B(^4\text{He}) \approx 10\%$

Λ **Hypernuclei** No OPE therefore breaking scale is $2m_\pi$

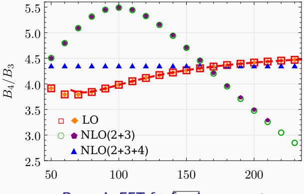
$$\left(\frac{Q}{M_h}\right) = \frac{\sqrt{2B_\Lambda M_\Lambda}}{2m_\pi} \approx 0.3$$

1. **Universality**
   - At LO, **2-body** inputs are **scattering lengths**
   - BEFT is well suited for studying universality

2. **The Wigner Bound** Phillips, Beane and Cohen (1997-1998)
   - The **effective range** is bounded by the cutoff $r_{\text{eff}} \leq W/\Lambda$
   - All orders but LO are perturbation (Kaplan, van Kolck, ...).

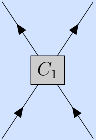
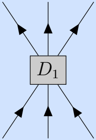
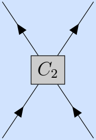
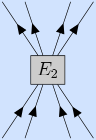
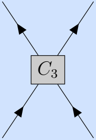
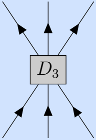
3. **The Thomas collapse** Bedaque, Hammer, and van Kolck (1999)
   - With LO 2-body interaction $B_3 \propto \hbar\Lambda^2/m.$
   - A **3-body** counter term must be introduced **at LO**.

4. **NLO - 4-body force** Bazak et al. (2019)
   - @NLO the 4-body system is unstable.
   - A **4-body** force promoted to **NLO**.



The Nuclear Interaction - BEFT/$\not\pi$EFT

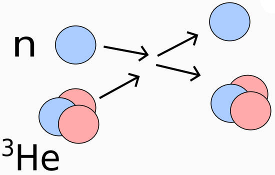
Kaplan, van Kolck, Bedaque, Hammer, Bazak, ...

	2-body	3-body	4-body	5-body
LO	 C_1	 D_1	–	–
NLO	 C_2	–	 E_2	–
N^2LO	 C_3	 D_3	?	?

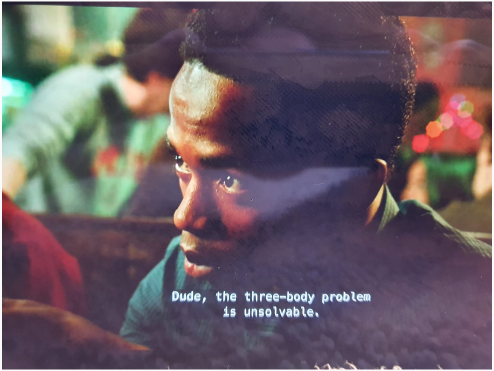
Bazak, Kirscher, König, Pavón Valderrama, Barnea, and van Kolck, PRL **122**, 143001 (2019)

Hammer, König and van Kolck, Rev. Mod. Phys. **92**, 025004 (2020)

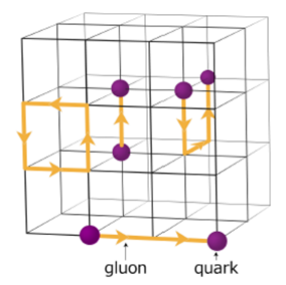
Light Nuclei



Study of nuclear scattering @NLO - **Martin's talk**

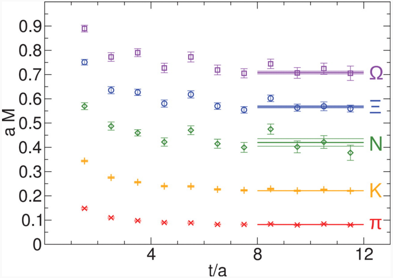


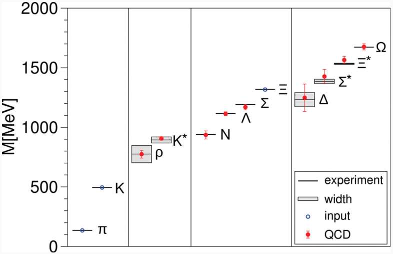
Lattice QCD



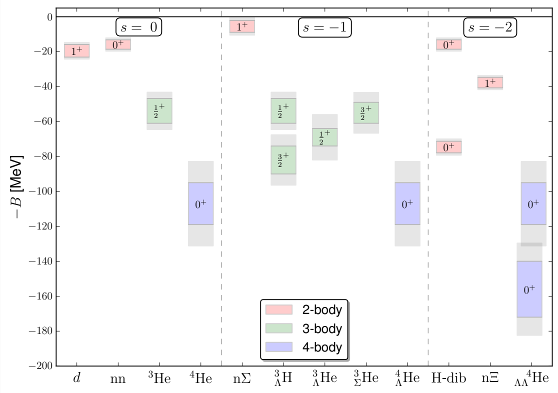
LQCD - The Single and Few Hadron Cases

- LQCD fulfilled its promise reproducing the baryonic spectrum
- Calculating the spectrum of **few-baryon systems** is a much harder challange
- There are different methodologies and controversies (e.g. NPLQCD vs HALQCD)





LQCD - Few-Baryon Spectrum



NPLQCD Collaboration, PRD **87**, 034506 (2013).

- **Nature**

  $m_u \approx m_d \ll m_s$

  $m_\pi \approx 140$ MeV

  $m_N \approx 939$ MeV.

- **SU(3) flavor symmetry**

  $m_u = m_d = m_s$

  $m_\pi \approx 806$ MeV

  $m_N \approx 1634$ MeV.

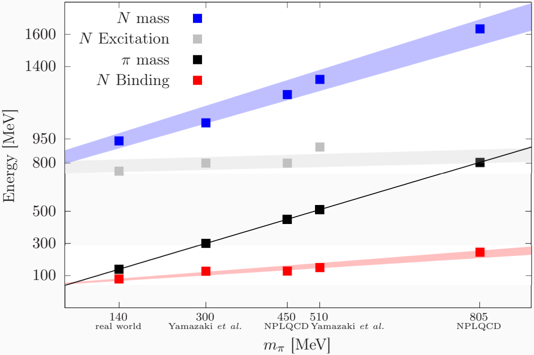
Energy Scales

- Baryon mass M_n, pion mass m_π
- Excitations, i.e. the mass difference $\Delta = M_\Delta - M_n$
- Pion exchange momentum $q_\pi = m_\pi/\hbar c$, and energy

$$E_\pi = \frac{\hbar^2 q_\pi^2}{M_n} = \frac{m_\pi}{M_n} m_\pi$$

- Nuclear binding energy $\sqrt{2M_n B/A}$

EFT for Lattice Nuclei

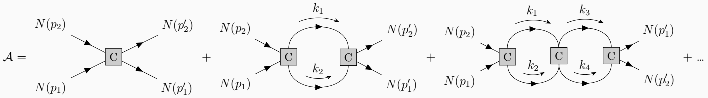


Conclusions

- For the Natural case $\mathcal{L} \longrightarrow \mathcal{L}_{EFT}(N,\pi)$ or $\mathcal{L}(N)$
- For lattice nuclei at $m_\pi \geq 300\text{MeV}$ $E_\pi \gg B/A$
- In this case $\not\pi$EFT is the natural theory $\mathcal{L} \longrightarrow \mathcal{L}_{EFT}(N)$

Barnea et al., PRL **114**, 052501 (2015)

$\not{\pi}$EFT for Lattice Nuclei

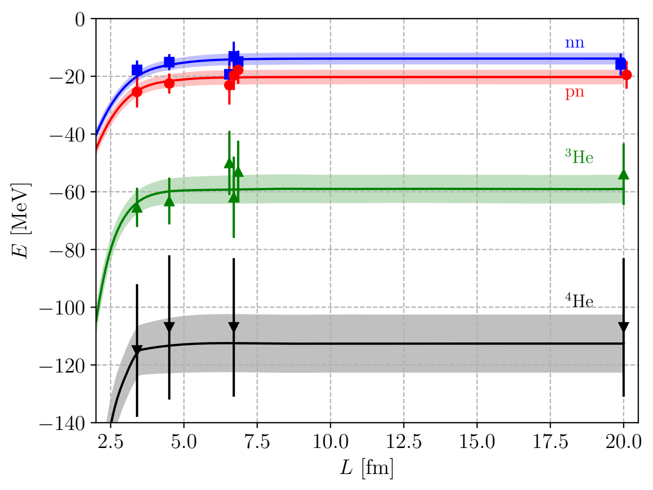


The LO Lagrangian for $\not{\pi}$EFT

$$\mathcal{L} = N^\dagger \left(i\partial_0 + \frac{\nabla^2}{2m} \right) N - \frac{C_1^{(1)}}{2} (N^\dagger N)^2 - \frac{C_2^{(1)}}{2} (N^\dagger \sigma N)^2 - \frac{D_1^{(1)}}{6} (N^\dagger N)^3$$

- At LO we have two 2-body contact terms
- One 3-body contact term.
- The 3-body term appears at LO to avoid the Thomas collapse.
- The coefficients depend on the cutoff Λ.
- Can be generalized to include electro-weak interactions

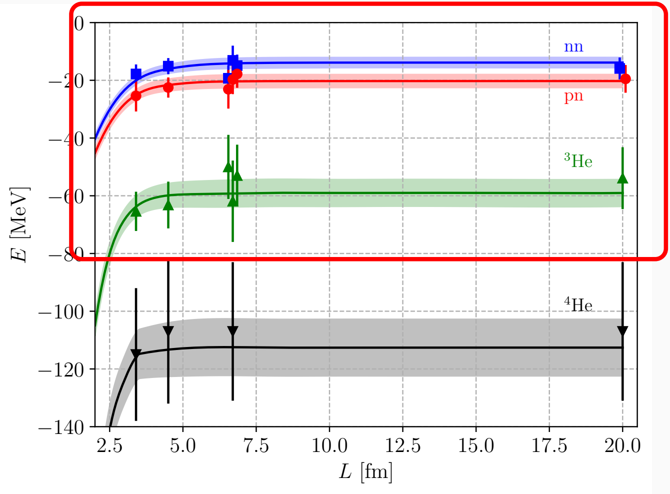
Matching in the box



Symbols: **NPLQCD - $m_\pi = 806$MeV**, Beane *et al.*, PRD **87**, 034506 (2013).

Curves: **$\not\pi$EFT**, Eliyahu, Bazak, and Barnea, PRC **102**, 044003 (2020).

Matching in the box



Fit the LECs

Symbols: **NPLQCD - $m_\pi = 806$MeV**, `Beane et al., PRD 87, 034506 (2013).`

Curves: **$\not\pi$EFT**, `Eliyahu, Bazak, and Barnea, PRC 102, 044003 (2020).`

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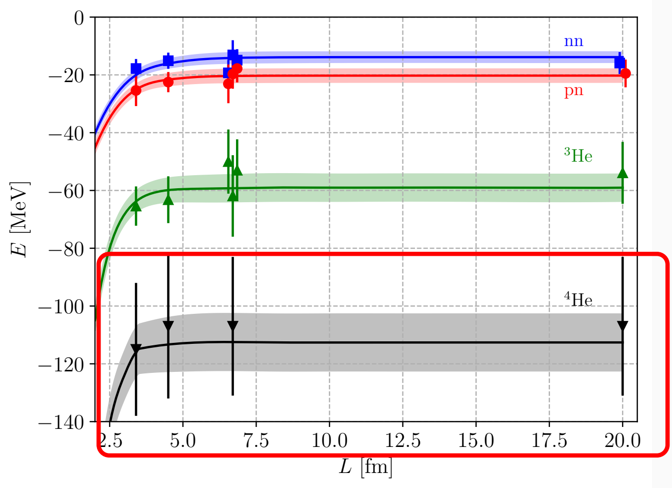
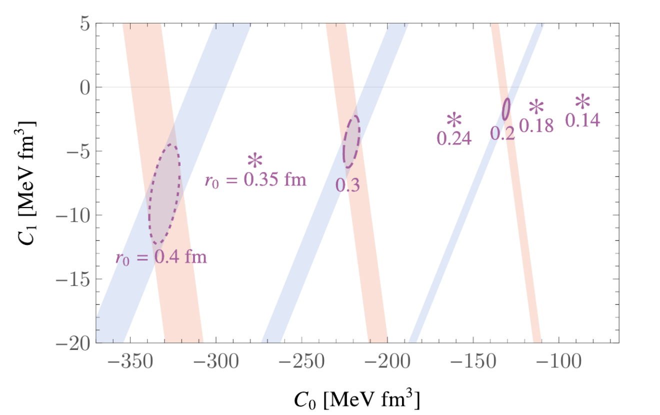


Prediction

Symbols: **NPLQCD - $m_\pi = 806$MeV**, `Beane et al., PRD 87, 034506 (2013).`

Curves: **$\not\pi$EFT**, `Eliyahu, Bazak, and Barnea, PRC 102, 044003 (2020).`

The 2-body LECs $(\Lambda = \sqrt{2}/r_0)$



Bands - **DS21**: `Detmold & Shanahan, PRD` **103** `074503 (2021)`

stars - **EBB20**: `Eliyahu, Bazak & Barnea, PRC` **102** `044003 (2020)`

`Figure taken from DS21`

Binding energies of the Light $A \leq 4$ nuclei

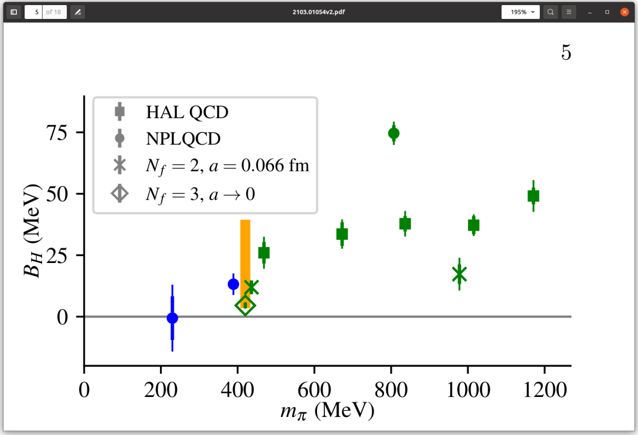
system	NPLQCD13	EBB20	DS21
nn	15.9 ± 3.8	13.8 ± 1.8	12.5 ± 2.2
^{2}H	19.5 ± 4.8	20.2 ± 2.3	19.9 ± 2.8
^{3}H	53.9 ± 10.7	58.2 ± 4.7	60.2 ± 6.5
^{4}He	107 ± 24	113 ± 10	

NPLQCD13: NPLQCD Collaboration, PRD **87** 034506 (2013)

EBB20: Eliyahu, Bazak & Barnea, PRC **102** 044003 (2020)

DS21: Detmold & Shanahan, PRD **103** 074503 (2021)

Few-Baryon in LQCD - Epilogue

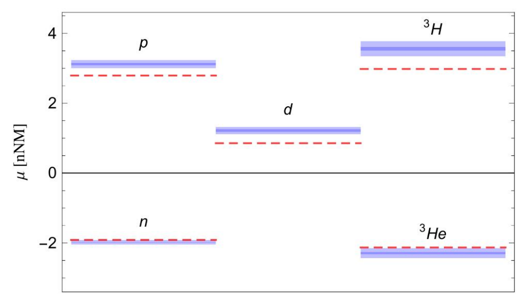


J. R. Green *et al.*, PRL 127, 242003 (2021)

Magnetic Moments etc.

Magnetic background fields

Magnetic moments and polarizations



$$\Delta E = \mu B + \frac{1}{2}\beta_M B^2$$

Chang et al. (NPLQCD Collaboration), PRD 92, 114502 (2015)

Magnetic field

The $\not\pi$EFT Lagrangian at NLO

$$\mathcal{L} = N^\dagger \left\{ (i\partial_0 - e\hat{Q}A_0) + \frac{1}{2m}\left(\boldsymbol{\nabla} - ie\hat{Q}\boldsymbol{A}\right)^2 + \hat{g}_\mu \frac{e}{2m}\boldsymbol{\sigma}\cdot\boldsymbol{B} \right\} N$$
$$+ C_T (N^\dagger P_i N)^2 + C_S (N^\dagger \bar{P}_3 N)^2 + D_1 (N^\dagger N)^3 + \dots$$
$$+ L_1 (N^\dagger P_i N)^\dagger (N^\dagger \bar{P}_3 N) B_i + L_2 i\epsilon_{ijk} (N^\dagger P_i N)(N^\dagger P_j N) B_k$$

The magnetic current

The one-body current

$$\boldsymbol{\mu}^{(1)} = \sum_{i=1}^{A} \frac{|e|}{2m}\left[\frac{g_p + g_n}{2}\boldsymbol{\sigma}_i + \frac{g_p - g_n}{2}\boldsymbol{\sigma}_i \boldsymbol{\tau}_{i,z}\right]$$

The two-body current

$$\boldsymbol{\mu}^{(2)} = \sum_{i<j}^{A} \left[L_1(\boldsymbol{\sigma}_i - \boldsymbol{\sigma}_j)(\boldsymbol{\tau}_{i,z} - \boldsymbol{\tau}_{j,z}) + L_2(\boldsymbol{\sigma}_i + \boldsymbol{\sigma}_j)\right]\delta_\Lambda(\boldsymbol{r}_{ij})$$

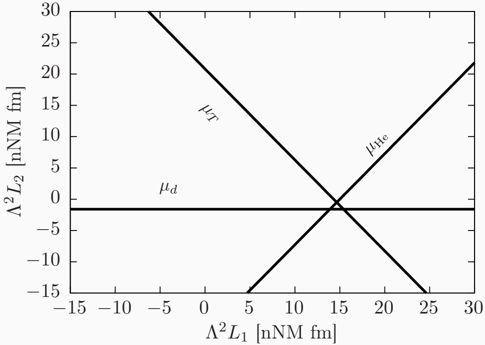
The magnetic LECs Kirscher, Pazy, Barnea

Observables

The deutron magnetic moment μ_d

The $A = 3$ magnetic moments $\mu_T, \mu_{^3\mathrm{He}}$

The transition matrix element $t_{01} = \langle {}^1S_0 | \boldsymbol{\mu} | {}^3S_1 \rangle$



Observations

$m_\pi = 140$MeV - Consistencey between the different observables

$m_\pi = 806$MeV - Error bars too large, t_{01} a bit off

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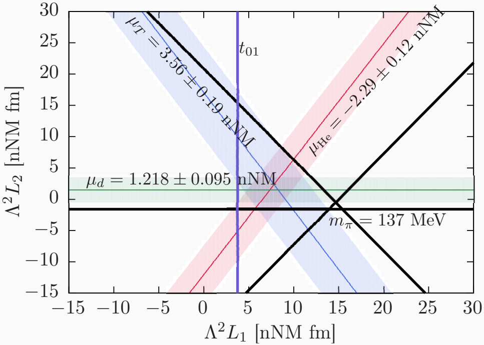

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Observables

The deuteron magnetic moment μ_d

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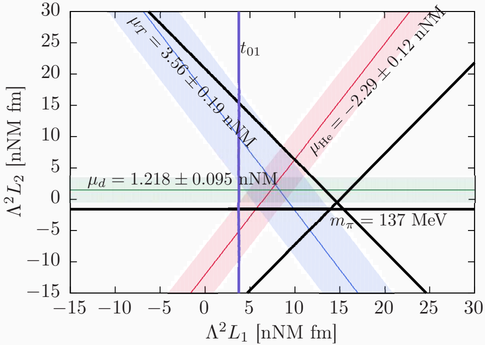

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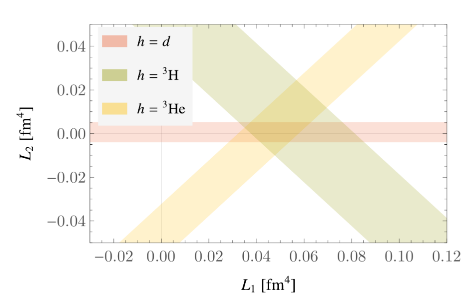
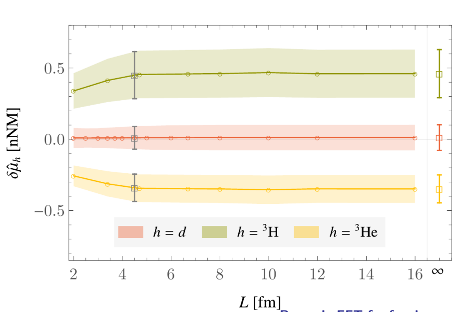
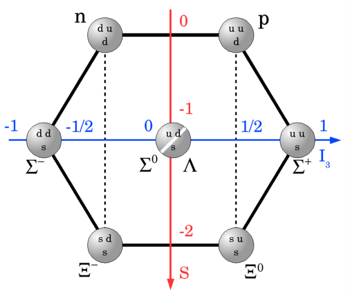


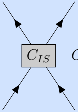
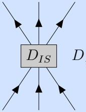
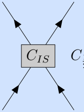
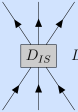
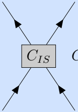
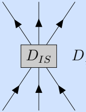


Detmold & Shanahan, PRD **103** 074503 (2021)

Light Hypernuclei @LO



2-body & 3-body diagrams:

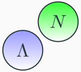
	2-body		**3-body**		#LECS
Strange = 0		$C_{01},\ C_{10}$		$D_{\frac{1}{2}\frac{1}{2}}$	3
Strange = -1		$C_{\frac{1}{2}0},\ C_{\frac{1}{2}1}$		$D_{0\frac{1}{2}},\ D_{0\frac{3}{2}},\ D_{1\frac{1}{2}}$	5
Strange = -2		C_{00}		$D_{\frac{1}{2}\frac{1}{2}}$	2

Contact terms
minimal amount of parameters

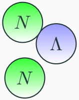
LECs
constrainted by exp. data

L. Contessi, M. Schafer, N. Barnea, A. Gal, J. Mareš, PLB 797 (2019) 134893

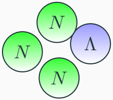
What do we have?

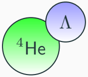


Not bound
scarce scattering data

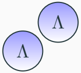


$^{3}_{\Lambda}$**H,** $B_\Lambda \approx 0.1$ **MeV**

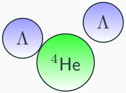




$^{4}_{\Lambda}$**H**^{0,1}**,**$^{4}_{\Lambda}$**He**^{0,1} $B_\Lambda \approx 3$ **MeV**
$^{5}_{\Lambda}$**He,** $B_\Lambda \approx 3$ **MeV**

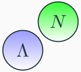


Not bound
scarce scattering data

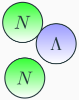


$^{6}_{\Lambda\Lambda}$**He,** $B_\Lambda \approx 3$ **MeV**

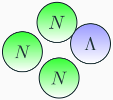
What do we have?

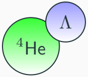


$C_{\frac{1}{2}0}$, $C_{\frac{1}{2}1}$

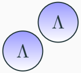


${}^3_\Lambda$**H**, $B_\Lambda \approx 0.1$ **MeV**

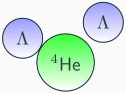




${}^4_\Lambda$**H**^{0,1},${}^4_\Lambda$**He**^{0,1} $B_\Lambda \approx 3$ **MeV**
${}^5_\Lambda$**He**, $B_\Lambda \approx 3$ **MeV**

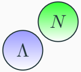


C_{00}

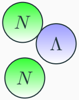


${}^{\ \ 6}_{\Lambda\Lambda}$**He**, $B_\Lambda \approx 3$ **MeV**

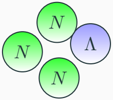
What do we have?

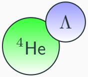


$C_{\frac{1}{2}0}$, $C_{\frac{1}{2}1}$



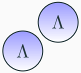
$D_{0\frac{1}{2}}$



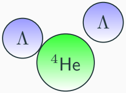


$D_{0\frac{3}{2}}$, $D_{1\frac{1}{2}}$

$^{5}_{\Lambda}$**He,** $B_\Lambda \approx 3$ **MeV**

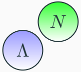


C_{00}

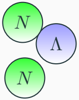


$^{6}_{\Lambda\Lambda}$**He,** $B_\Lambda \approx 3$ **MeV**

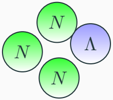
What do we have?

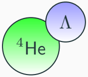


$C_{\frac{1}{2}0}$, $C_{\frac{1}{2}1}$



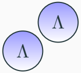
$D_{0\frac{1}{2}}$



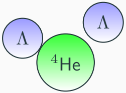


$D_{0\frac{3}{2}}$, $D_{1\frac{1}{2}}$

$^5_\Lambda$**He,** $B_\Lambda \approx 3$ **MeV**



C_{00}



$D_{\frac{1}{2}\frac{1}{2}}$

ΛN scattering data

- Cross-sections for $p_{lab} \geq 100$ MeV/c
- Spin dependence not resolved

- **Alexander et al.** PR173, 1452 (1968)

  $$a^0_{\Lambda N} = -1.8^{+2.3}_{-4.2} \text{ fm}$$
  $$a^1_{\Lambda N} = -1.6^{+1.1}_{-0.8} \text{ fm}$$

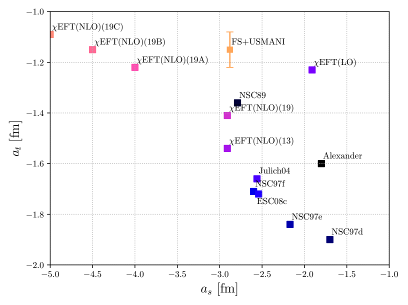
- **Sechi-Zorn et al.** PR175, 1735 (1968)

  $$0 > a^0_{\Lambda N} > -9.0 \text{ fm}$$
  $$-0.8 > a^1_{\Lambda N} > -3.2 \text{ fm}$$

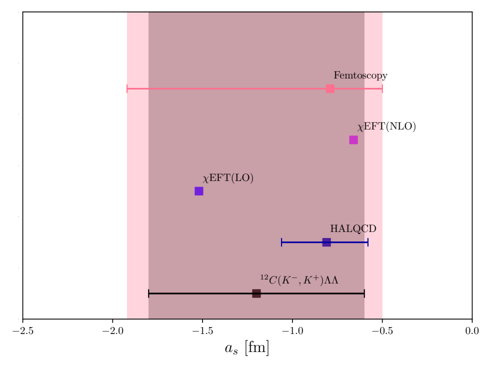
- **Femtoscopy** (2023)

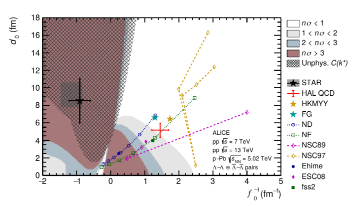
  Tight constraint on a_s, a_t

  inconsistent with existing models



ΛΛ scattering lengths





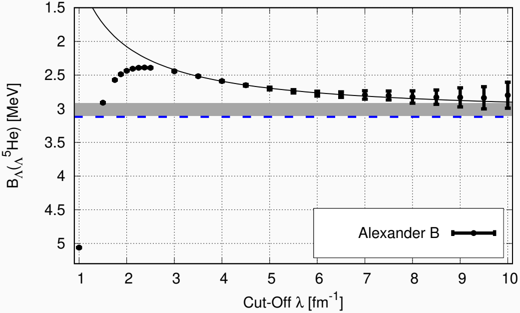
ALICE Collaboration, PLB 797, 134822 (2019)

ΛΛ scattering length

Exp./Model	$a^0_{\Lambda\Lambda}$ [fm]	
^{12}C$(K^-,K^+)\Lambda\Lambda X$	$-1.2(6)$	PRC 85, 015204 (2012)
HALQCD	$-0.81 \pm 0.23^{0.0}_{-0.1}$	NPA 998, 121737 (2020)
χEFT(LO;600)	-1.52	PLB 653, 29 (2007)
χEFT(NLO;600)	-0.66	NPA 954, 273 (2016)
Femtoscopy	$-0.79^{+0.29}_{-1.13}$	PRC 91, 024916 (2016)
		PRL 114, 022301 (2015)

The $^{5}_{\Lambda}$He binding energy

$B_\Lambda(^5_\Lambda$He) vs. cut-off λ in LO BEFT



L.Contessi N.Barnea A.Gal, PRL 121 (2018) 102502

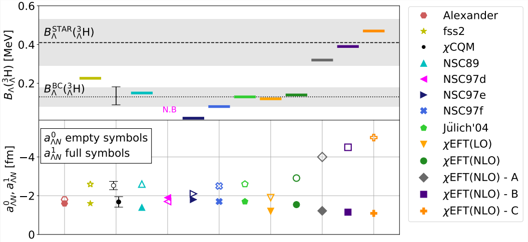
With Alexander & χEFT(NLO) scattering lengths a_s, a_t
$B_\Lambda(^5_\Lambda$He) is reproduced within theoretical error

Cut-off dependence

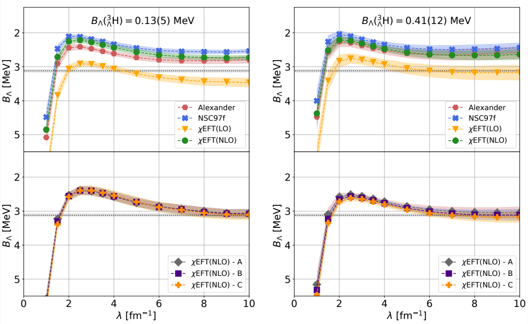
$$\frac{B_\Lambda(\lambda)}{B_\Lambda(\infty)} = 1 + \frac{\alpha}{\lambda} + \frac{\beta}{\lambda^2} + \dots$$

$^{5}_{\Lambda}$He - The impact of “Deep” hypertriton

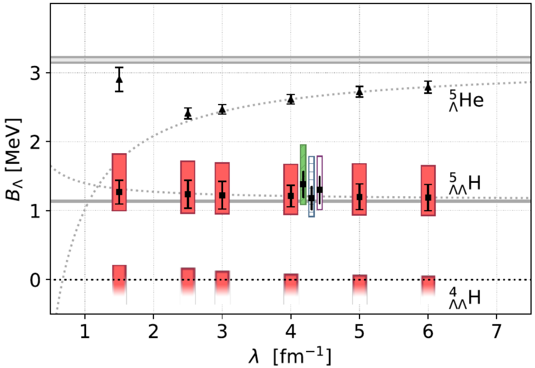
Scattering lengths



$^{5}_{\Lambda}$He Binding energy



האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

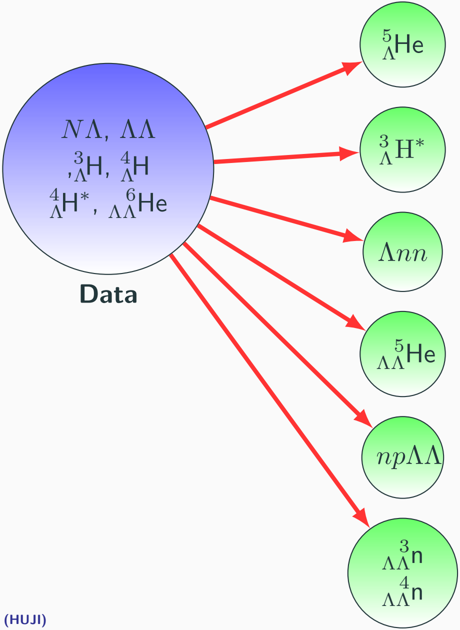


Contessi-Schafer-Barnea-Gal-Mareš, PLB 797 (2019) 134893.

Double-Λ systems:

- The neutral systems $\Lambda\Lambda n$, $\Lambda\Lambda nn$ are not bound
- $^4_{\Lambda\Lambda}$H on verge of binding. Better data is needed for clarification.
- In our theory $^5_{\Lambda\Lambda}$H is comfortably bound

Hypernuclear BEFT/$\not\pi$EFT in a nut shell



No overbinding problem!

Virtual state

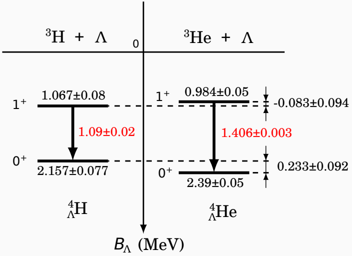
Physical resonance?

Solidaly bound

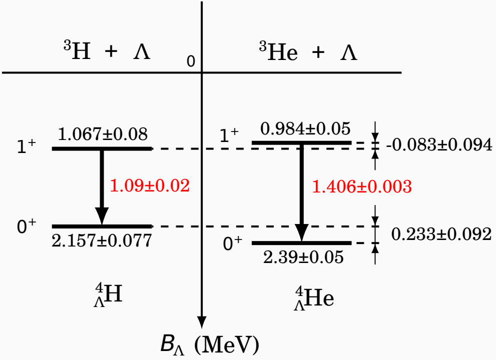
Marginal case

Unbound

Charge symmetry breaking



$A = 4$ hypernuclear level scheme



- $B_\Lambda({}^4_\Lambda\mathrm{He}; 0^+)$ - **Emulsion measurement**

  Nucl. Phys. A 754, 3c (2005)

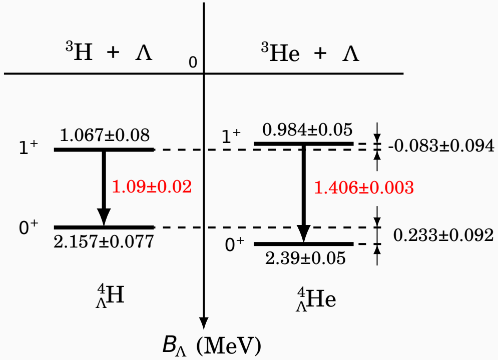
- $B_\Lambda({}^4_\Lambda\mathrm{H}; 0^+)$ - **MAMI experiment**

  Nucl. Phys. A 954, 149 (2016)

- $E_\gamma({}^4_\Lambda\mathrm{H}; 1^+ \to 0^+)$, $E_\gamma({}^4_\Lambda\mathrm{He}; 1^+ \to 0^+)$ - **γ-rays at J-PARC**

  Phys. Rev. Lett. 115, 222501 (2015)

$A = 4$ hypernuclear level scheme



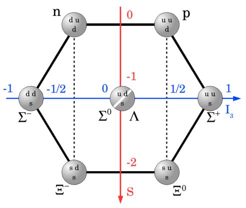
- **Charge symmetry:** invarince under $n \leftrightarrow p$, e.g. $^3\mathrm{H} \leftrightarrow {}^3\mathrm{He}$
- **Nuclei:** for $^3\mathrm{He}$ - $^3\mathrm{H}$, ΔE_{CSB} without Coulomb is about 70 keV
- For $^3\mathrm{He}$ - $^3\mathrm{H}$: $\Delta E_{CSB}/\Delta E \approx 0.01$
- **Hypernuclei:** CSB in $^4_\Lambda$He-$^4_\Lambda$H: $\Delta E_{CSB}/\Delta E \approx 0.22$

Theoretical considerations

Dalitz, von Hippel Phys. Lett. 10, 153 (1964)
$\Lambda - \Sigma^0$ mixing in $\mathrm{SU}(3)_f$ (following Coleman & Glashow)

$$\mathcal{A}^{(0)}_{I=1} = -\frac{\langle \Sigma^0 | \delta M | \Lambda \rangle}{M_{\Sigma^0} - M_\Lambda} = -0.0148(6)$$

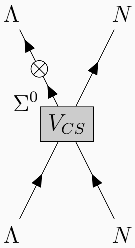
CSB OPE contribution by $g_{\Lambda\Lambda\pi} = 2\mathcal{A}^{(0)}_{I=1} g_{\Lambda\Sigma\pi}$



- **A. Gal** Phys. Lett. B 744, 352, (2015)
  Generalization of DvH

$$\langle \Lambda N | V_{\mathrm{CSB}} | \Lambda N \rangle = -\frac{2}{\sqrt{3}} \mathcal{A}^{(0)}_{I=1} \langle \Sigma N | V_{\mathrm{CS}} | \Lambda N \rangle \, \tau_z .$$

$\Delta B_\Lambda(0^+) \approx 240$ keV $\quad$ $\Delta B_\Lambda(1^+) \approx 35$ keV



- **Gazda, Gal** PRL 116, 122501 (2016)
  generalized DvH; LO χEFT YN interaction; NSCM

$\Delta B_\Lambda(0^+) \approx 180 \pm 130$ keV $\quad$ $\Delta B_\Lambda(1^+) \approx -200 \pm 30$ keV

Charge symmetry breaking - χEFT

Observations:

- π, K terms negligible
- CSB is short range physics
- 2 d.p. and 2 parameters C_s^{CSB}, C_t^{CSB}
- $S = 0, 1$ have **opposite signs**
- Spin **singlet dominance**

$$|C_s^{CSB}| \gg |C_t^{CSB}|$$

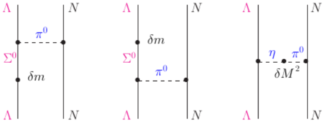


Fig. 1 CSB contributions involving pion exchange, according to Dalitz and von Hippel [1], due to $\Lambda - \Sigma^0$ mixing (left two diagrams) and $\pi^0 - \eta$ mixing (right diagram).

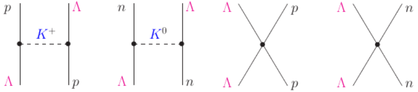


Fig. 2 CSB contributions from $K^{\pm}/K^0$ exchange (left) and from contact terms (right).

Λ	NLO13		NLO19	
	C_s^{CSB}[MeV^{-2}]	C_t^{CSB}[MeV^{-2}]	C_s^{CSB}[MeV^{-2}]	C_t^{CSB}[MeV^{-2}]
500	4.691×10^{-3}	-9.294×10^{-4}	5.590×10^{-3}	-9.505×10^{-4}
550	6.724×10^{-3}	-8.625×10^{-4}	6.863×10^{-3}	-1.260×10^{-3}
600	9.960×10^{-3}	-9.870×10^{-4}	9.217×10^{-3}	-1.305×10^{-3}
650	1.500×10^{-2}	-1.142×10^{-3}	1.240×10^{-2}	-1.395×10^{-3}

Question:

Can BEFT explain these last 2 observations?

Haidenbauer et al., Few-body sys. (2019)

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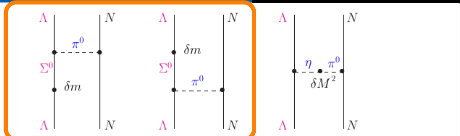

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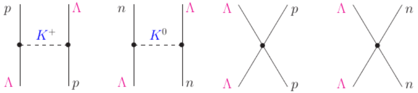

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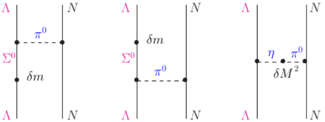


Fig. 1 CSB contributions involving pion exchange, according to Dalitz and von Hippel [1], due to $\Lambda - \Sigma^0$ mixing (left two diagrams) and $\pi^0 - \eta$ mixing (right diagram).

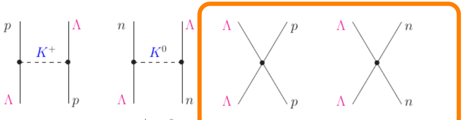


Fig. 2 CSB contributions from $K^{\pm}/K^0$ exchange (left) and from contact terms (right)

Λ	NLO13		NLO19	
	C_s^{CSB}[MeV^{-2}]	C_t^{CSB}[MeV^{-2}]	C_s^{CSB}[MeV^{-2}]	C_t^{CSB}[MeV^{-2}]
500	4.691×10^{-3}	-9.294×10^{-4}	5.590×10^{-3}	-9.505×10^{-4}
550	6.724×10^{-3}	-8.625×10^{-4}	6.863×10^{-3}	-1.260×10^{-3}
600	9.960×10^{-3}	-9.870×10^{-4}	9.217×10^{-3}	-1.305×10^{-3}
650	1.500×10^{-2}	-1.142×10^{-3}	1.240×10^{-2}	-1.395×10^{-3}

Haidenbauer et al., Few-body sys.

(2019)

Question:

Can BEFT explain these last 2 observations?

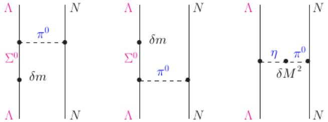
Observations:

- π, K terms negligible
- CSB is short range physics
- 2 d.p. and 2 parameters C_s^{CSB}, C_t^{CSB}
- $S = 0, 1$ have **opposite signs**
- Spin **singlet dominance**

$$|C_s^{CSB}| \gg |C_t^{CSB}|$$

Question:

Can BEFT explain these last 2 observations?



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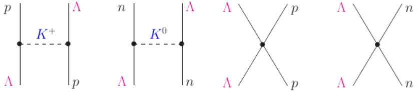

Fig. 2 CSB contributions from $K^{\pm}/K^0$ exchange (left) and from contact terms (right).

Λ	NLO13		NLO19	
	C_s^{CSB} [illegible]	[illegible]	[illegible]	[illegible]
500	[illegible]	[illegible]	[illegible]	[illegible]
550	[illegible]	[illegible]	[illegible]	[illegible]
600	9.960×10^{-3}	-9.870×10^{-4}	9.217×10^{-3}	-1.305×10^{-3}
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1.240×10^{-2} $\quad -1.395 \times 10^{-3}$

Haidenbauer et al., Few-body sys. (2019)

Charge Symmetric ΛN

$$V_{\Lambda N} = \sum_S C^S_{\Lambda N}(\lambda)\mathcal{P}_S \delta_\lambda(\boldsymbol{r})$$

CSB ΛN interaction

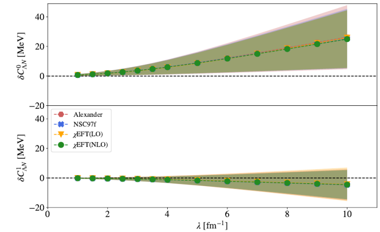
$$C^S_{\Lambda N} \to \left[C^S_{\Lambda p}\frac{1+\tau_z}{2} + C^S_{\Lambda n}\frac{1-\tau_z}{2} \right]$$

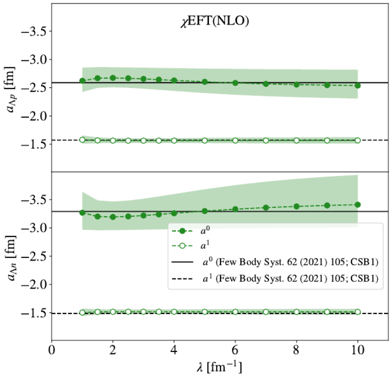
Resulting LECs

$$C^S_{\Lambda N} = \frac{1}{2}\left(C^S_{\Lambda p} + C^S_{\Lambda n}\right)$$

$$\Delta C^S_{\Lambda N} = \frac{1}{2}\left(C^S_{\Lambda p} - C^S_{\Lambda n}\right)$$

Same observations as in χEFT





The DvH mechanism in BEFT

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

Dalitz, von Hippel for BEFT

$$\langle \Lambda N | C_{\rm CSB} | \Lambda N \rangle = -\frac{2}{\sqrt{3}}\, \mathcal{A}^{(0)}_{I=1}\, \langle \Sigma N | C_{\rm CS} | \Lambda N \rangle\, \tau_z \,.$$

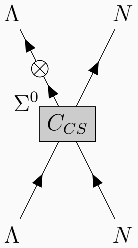
Assuming $\mathrm{SU(3)_f}$ symmetry we can relate $C^S_{\Lambda N,\Sigma N}$ to the NN and ΛN LECs:

$$C^0_{\Lambda N,\Sigma N} = -3(C^0_{NN} - C^0_{\Lambda N}),$$
$$C^1_{\Lambda N,\Sigma N} = \quad (C^1_{NN} - C^1_{\Lambda N}).$$

Dover, Feshbach, Ann. Phys. (NY) 198, 321 (1990)

The resulting CSB LECs are opposite in sign and

$$|C_s^{CSB}| \gg |C_t^{CSB}|$$



Having $\mathcal{A}^{(0)}_{I=1}$ we have **no free parameters**.

Now we can go in the other direction and **predict** $\mathcal{A}^{(0)}_{I=1}$ from the hypernuclear spectrum.

Dalitz, von Hippel for BEFT

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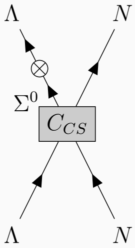

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The DvH mechanism in BEFT

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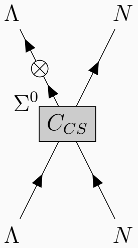

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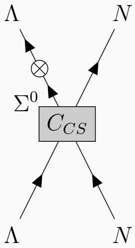

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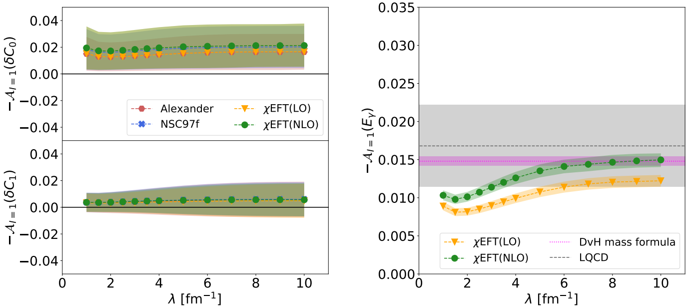

Method/Input	$-\mathcal{A}_{I=1}$
$\mathrm{SU}(3)_\mathrm{f}$ [DvH64]	0.0148 ± 0.0006
LQCD [LQCD20]	0.0168 ± 0.0054
$\not\pi$EFT(LO)/χEFT(LO) [Polinder06]	0.0139 ± 0.0013
$\not\pi$EFT(LO)/χEFT(NLO) [Haidenbauer13]	0.0168 ± 0.0014

Conclusions

Collaboration

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