Progress & issues in Strangeness NP

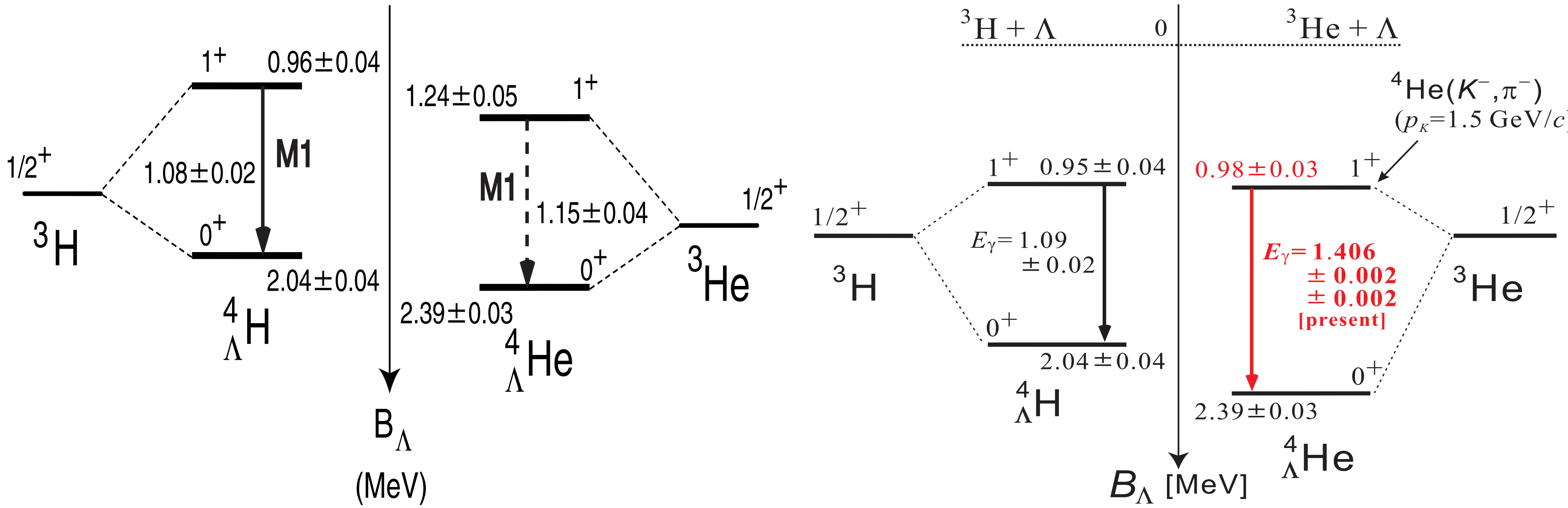
Avraham Gal, Hebrew University, Jerusalem

- $\mathcal{S} = -1$: **dynamics of Λ hypernuclei ($^{A}_{\Lambda}Z$)**
  (i) Λ few-body & (ii) neutron-rich systems
  (iii) Λ and other hyperons in neutron stars?
- **$\Lambda\Lambda$ hypernuclei: long-lived H dibaryon?**
- **Hyperons (Λ, Σ, Ξ) in nuclear matter**
  $|\mathcal{S}| \to \infty$: **strange hadronic matter?**
- **Kaons in nuclei:** K^- **quasibound states?**
  Θ^+**(1540) traces in** K^+ **nuclear dynamics?**
- **SNP Special Issue: Nucl. Phys. A 881 (2012)**
  Proc. HYP 2012: Nucl. Phys. A 914 (2013)

Λ hypernuclear dynamics

${}^4_\Lambda$H–${}^4_\Lambda$He levels before and after J-PARC E13 exp.

T. O. Yamamoto et al., J-PARC-E13, PRL 115 (2015) 222501

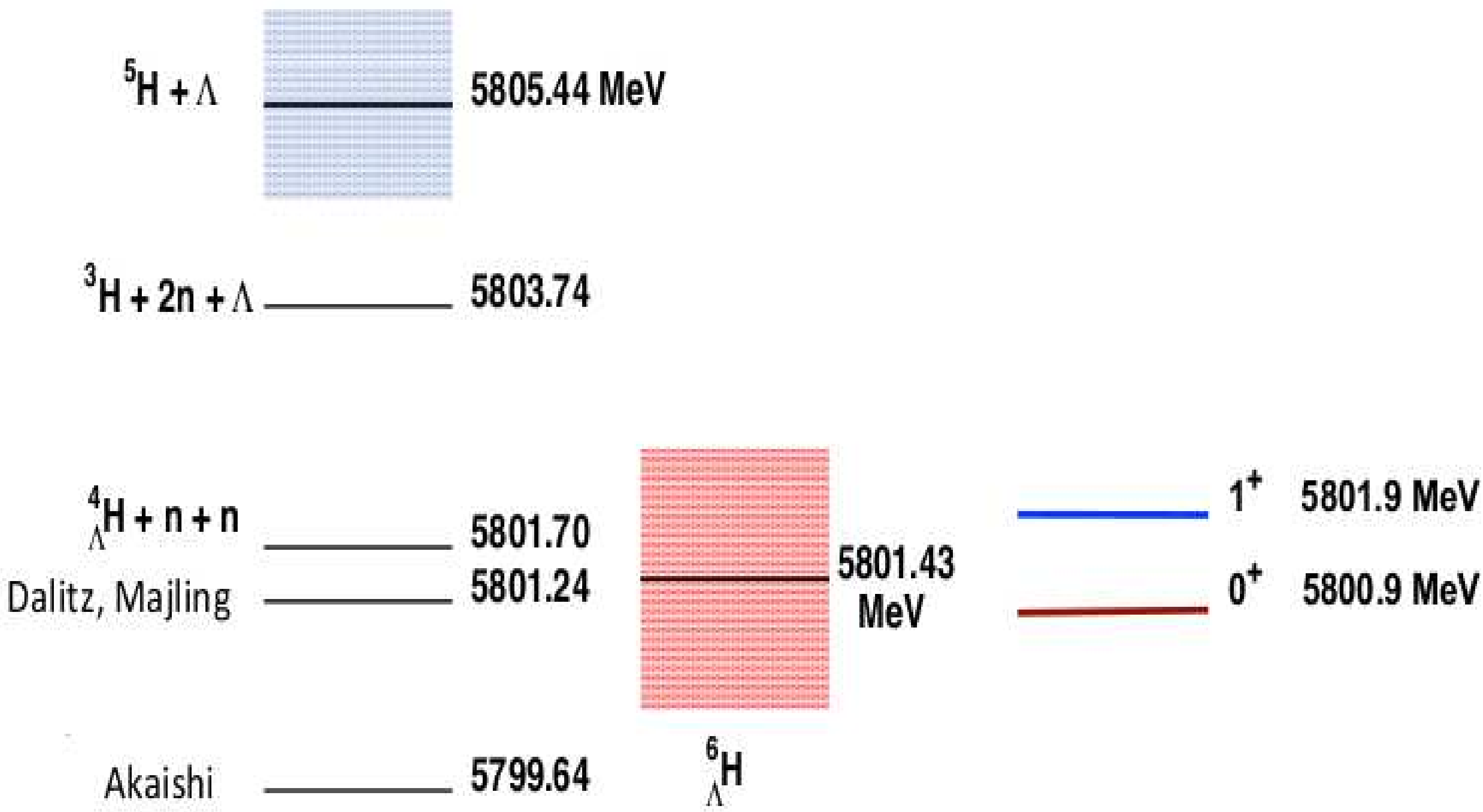


MAMI's new value $B_\Lambda({}^4_\Lambda\mathrm{H})$=2.12±0.01±0.09 MeV, consistent with emulsion value, obtained by measuring decay π^- in ${}^4_\Lambda\mathrm{H}\rightarrow{}^4\mathrm{He}+\pi^-$ [PRL 114 (2015) 232501].

CSB is strongly spin dependent, dominantly in $0^+_{\mathrm{g.s.}}$

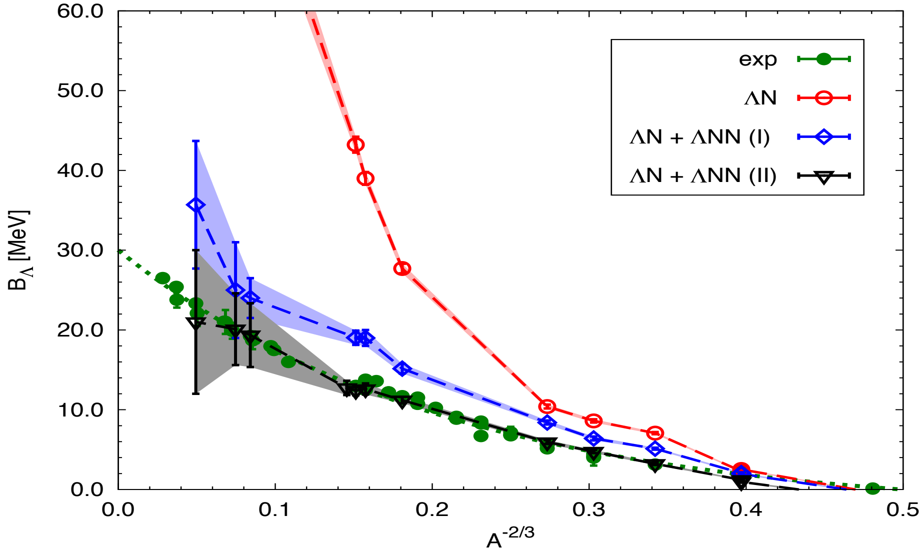
350±60 keV in ${}^4_\Lambda$H-${}^4_\Lambda$He vs. ≈−70 keV in ^{3}H-^{3}He.

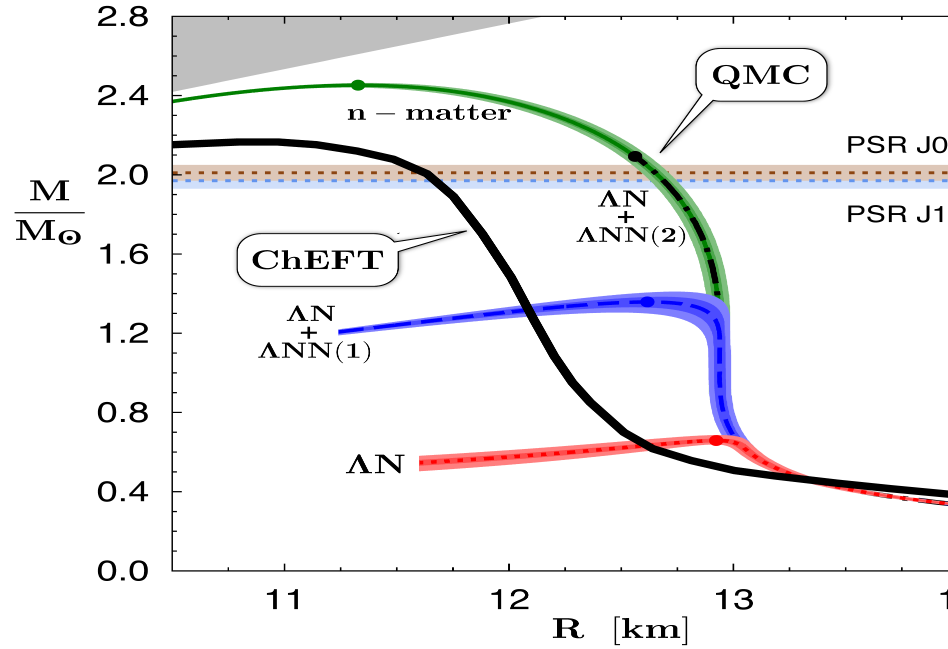
FINUDA+Gal (2012) [PRL 108, 042501; NPA 881, 269]



- **Three ${}^{6}_{\Lambda}$H candidate events out of 2.7 x 10^7 $K^-_{\rm stop}$.**
- **$B_\Lambda({}^{6}_{\Lambda}$H) constrains $\Lambda N \leftrightarrow \Sigma N$ effects in neutron-rich ${}^{A}_{\Lambda}Z$.**

Hyperon puzzle: QMC calculations





Lonardoni et al, PRC 89 (2014) 014314

PRL 114 (2015) 092301

ΛNN effect on B_Λ(g.s.)

ΛNN effect on neutron stars

- **Adding ΛNN (and YY) stiffens EOS of neutron stars.**
- **Σ & Ξ hyperons need to be considered too.**
- **YY add 0.3$M_\odot$ to M_{max} (Rijken-Schulze 2016).**

$\Lambda\Lambda$ hypernuclei

Binding energy consistency of ΛΛ hypernuclei

event	${}^{A}_{\Lambda\Lambda}Z$	$B^{exp}_{\Lambda\Lambda}$	$B^{CM}_{\Lambda\Lambda}$ †	$B^{SM}_{\Lambda\Lambda}$ ††
E373-Nagara	${}^{6}_{\Lambda\Lambda}He$	6.91 ± 0.16	6.91 ± 0.16	6.91 ± 0.16
E373-DemYan	${}^{10}_{\Lambda\Lambda}Be$	14.94 ± 0.13 ‡	14.74 ± 0.16	14.97 ± 0.22
E373-Hida	${}^{11}_{\Lambda\Lambda}Be$	20.83 ± 1.27	18.23 ± 0.16	18.40 ± 0.28
E373-Hida	${}^{12}_{\Lambda\Lambda}Be$	22.48 ± 1.21	–	20.72 ± 0.20
E176	${}^{13}_{\Lambda\Lambda}B$	23.4 ± 0.7 *	–	23.21 ± 0.21

† E. Hiyama et al., PRL **104** (2010) 212502, & refs. therein

†† A. Gal, D.J. Millener, PLB **701** (2011) 342

‡ Assuming production in ${}^{10}_{\Lambda\Lambda}Be$ 1st excited state 2^+(3.04 MeV)

* Assuming ${}^{13}_{\Lambda\Lambda}B_{g.s.}$ decay to ${}^{13}_{\Lambda}C^*(5/2^+, 3/2^+;\ 4.8\ \text{MeV}) + \pi^-$

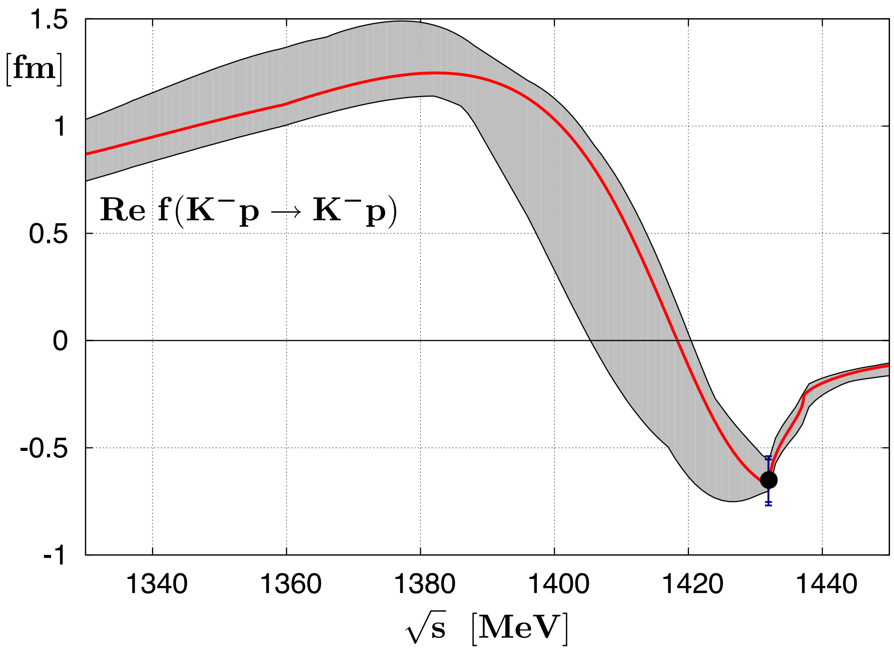
- Hida-event [PTPS **185** (2010) 335] offers no clue
- $B^{SM}_{\Lambda\Lambda} \approx B^{CM}_{\Lambda\Lambda}$, but SM spans a wider A range

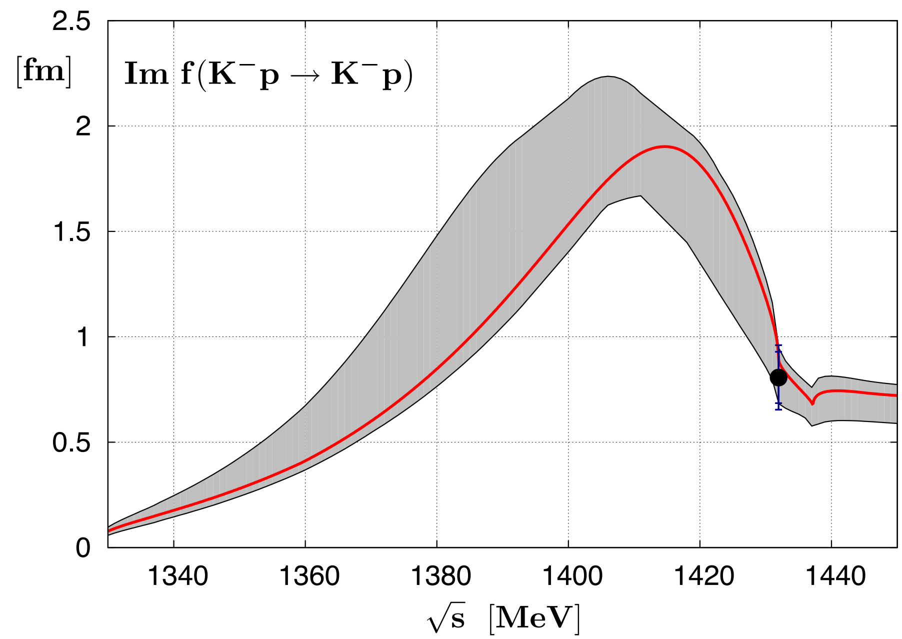
$\Lambda\Lambda$ conclusions

- Relatively weak $\Lambda\Lambda$ interaction
  $< V_{\Lambda\Lambda} > \approx 0.6$ MeV, $|a_{\Lambda\Lambda}| < 1$ fm
- Onset of $\Lambda\Lambda$ binding likely with ${}^{5}_{\Lambda\Lambda}$H & ${}^{5}_{\Lambda\Lambda}$He
- Shell model works well beyond ${}^{6}_{\Lambda\Lambda}$He
- No sound SM or CM interpretation for Hida event
- Need more data for systematics and for studying possible continuum effects from H dibaryon
- J-PARC E07: $\mathcal{S} = -2$ emulsion-counter studies
- J-PARC E42: search for H dibaryon in (K^-, K^+)
- FAIR (PANDA): slowing down Ξ^- from $\bar{p}p \to \Xi^-\bar{\Xi}^+$

Kaons in nuclei

$K^- p$ scattering amplitude from NLO chiral SU(3) dynamics





Y. Ikeda, T. Hyodo, W. Weise (IHW), PLB **706** (2011) 63; NPA **881** (2012) 98

Threshold f(K^-p) given by SIDDHARTA K^-H experiment

PLB 704 (2011) 113, NPA 881 (2012) 88. Need f(K^-n)$\rightarrow$ do K^-d.

Strong subthreshold $K^- p$ attraction; $\Lambda(1405)$ physics;

consequences for kaonic atoms & nuclear clusters; e.g. K^-pp

K^-pp quasibound state B & Γ (calc.)

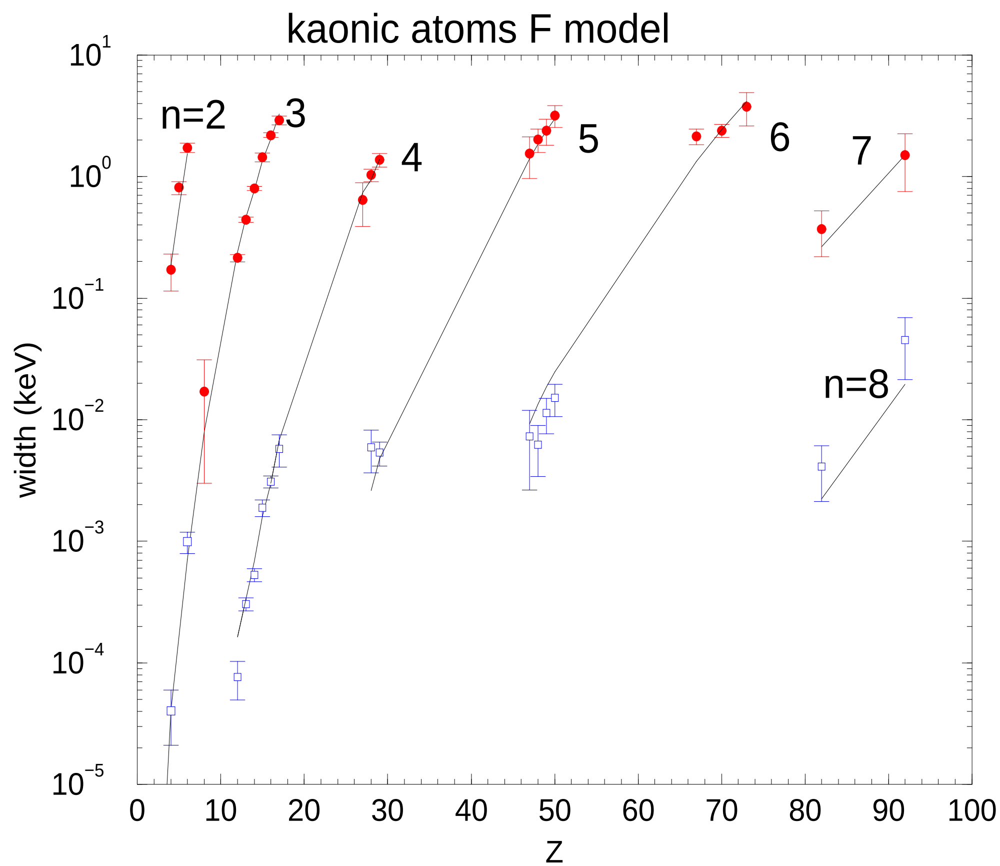
(MeV)	chiral, energy dep. calculations				non-chiral, static calculations			
	var. [1]	var. [2]	Fad. [3]	Fad. [4]	var. [5]	Fad. [6]	Fad. [7]	var. [8]
B	16	17–23	9–16	32	48	50–70	60–95	40–80
Γ	41	40–70	34–46	49	61	90–110	45–80	40–85

Robust binding & large widths; weak binding in χEFT models.

Recent searches at J-PARC (E15 & E27) are inconclusive.

1. N. Barnea, A. Gal, E.Z. Liverts, PLB 712 (2012) 132
2. A. Doté, T. Hyodo, W. Weise, NPA 804 (2008) 197, PRC 79 (2009)
3. Y. Ikeda, H. Kamano, T. Sato, PTP 124 (2010) 533
4. J Revai, N.V. Shevchenko, PRC 90 (2014) 034004
5. T. Yamazaki, Y. Akaishi, PLB 535 (2002) 70
6. N.V. Shevchenko, A. Gal, J. Mareš, PRL 98 (2007) 082301
7. Y. Ikeda, T. Sato, PRC 76 (2007) 035203, PRC 79 (2009) 035201
8. S. Wycech, A.M. Green, PRC 79 (2009) 014001 (including p waves)

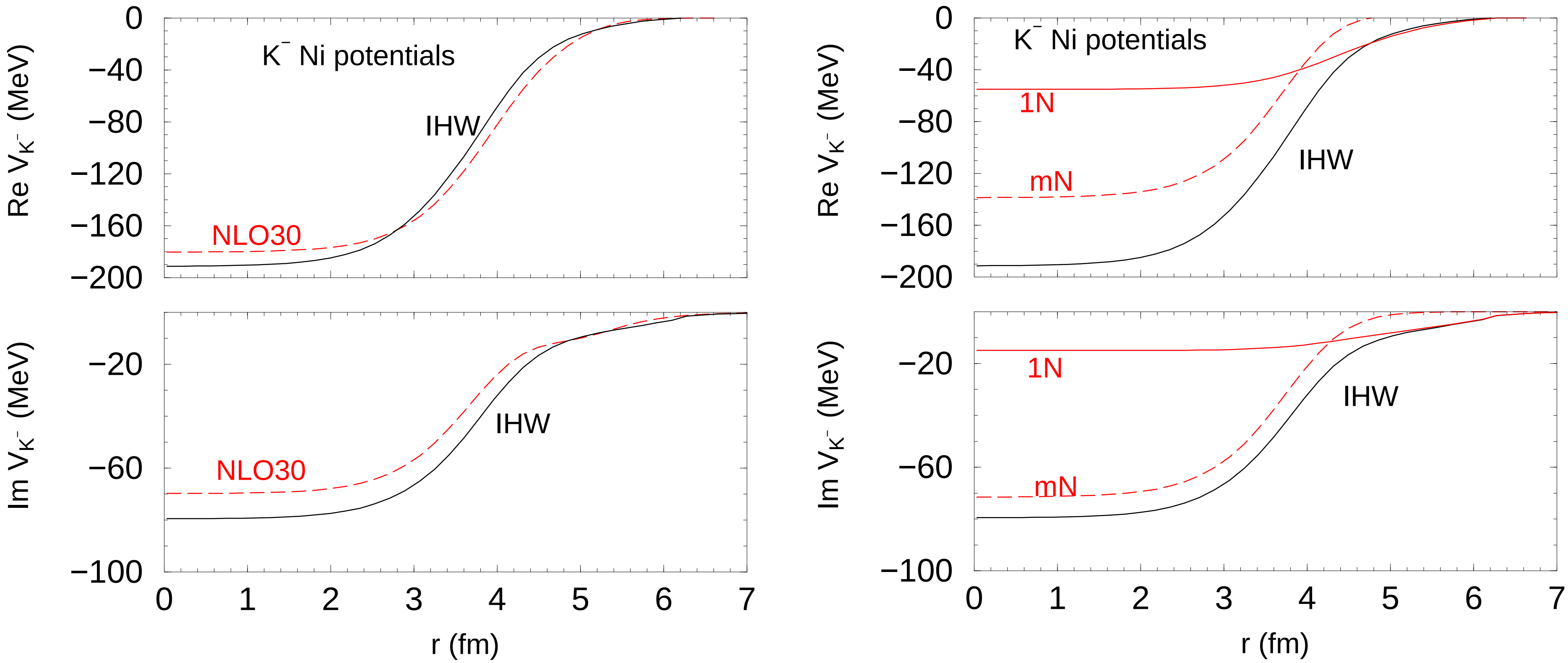
What do K^- atoms tell us?



$K^-_{\rm atom}$ widths in a best-fit deep potential.

$\chi^2 = 84$ per 65 data points across the periodic table.

E. Friedman, A. Gal, Phys. Rep. 452 (2007) 89.



NLO30: A. Cieply, J. Smejkal, NPA 881 (2012) 115 (in-medium).
IHW: Y. Ikeda, T. Hyodo, W. Weise, NPA 881 (2012) 98.

Kaonic-atom best-fit V_{K^-} for Ni & its breakdown into in-medium 1N and empirical m(any)N contributions.

Best-fit $\chi^2/\mathrm{N}^{\mathrm{atom}}_{\mathrm{data}}$=118/65 Friedman-Gal, NPA 899 (2013) 60.

Upper level sensitive to 1N & lower level to mN terms.

Measure both selectively [Friedman-Okada, NPA 915 (2013) 170].

Summary & Outlook

- ΛN **hypernuclear spin dependence deciphered.**
- **How small is** Λ **spin-orbit splitting and why?**
- **Role of 3-body** ΛNN **interactions?**
- **Search for n-rich** ${}^{A}_{\Lambda}\mathrm{Z}$; ${}^{6}_{\Lambda}\mathrm{H}$? **(E10).**
- **Re-measure the** ${}^{4}_{\Lambda}\mathrm{H}$–${}^{4}_{\Lambda}\mathrm{He}$ **complex (E13).**
- **Repulsive** Σ**-nuclear interaction; how repulsive?**
- **Onset of** $\Lambda\Lambda$ **binding:** ${}_{\Lambda\Lambda}{}^{4}\mathrm{H}$ **or** ${}_{\Lambda\Lambda}{}^{5}\mathrm{Z}$? **(E07).**
- **Do** Ξ **hyperons quasi-bind in nuclei** $(\Xi N \to \Lambda\Lambda)$**?**
  No quasibound Ξ **established yet (E05).**
- **Onset of** Ξ **stability:** ${}_{\Lambda\Xi}{}^{6}\mathrm{He}$ **or** ${}_{\Lambda\Lambda\Xi}{}^{7}\mathrm{He}$?

- **Search for K$^-$pp** $[\Lambda^*$**N(I=**$\frac{1}{2}$**,J**$^\pi$**=0**$^-$) **dibaryon**].
- **Is there** Σ^***N(I=**$\frac{3}{2}$**,J**$^\pi$**=2**$^+$) **dibaryon?**
- **No** $\bar{K}$ **condensation in self-bound matter.**
  $\{N, \Lambda, \Xi\}$ **provides Strange-Hadronic-Matter g.s.**
- **Do** K^-d **(SIDDHARTA-2) to constrain** K^-n.
- **Establish experimental program for precise** K^- **atom selective measurements.**
- **Search for** $\Theta^+(1540)$ **pentaquark traces in nuclei by doing (K**$^+$**,p), driven by K**$^+$**np** $\to$ Θ^+**p.**
- **Resolve the** $^3_\Lambda$**H lifetime puzzle from HIC.**

J-PARC SNP Experiments: Stage-1 Stage-2 Day-1

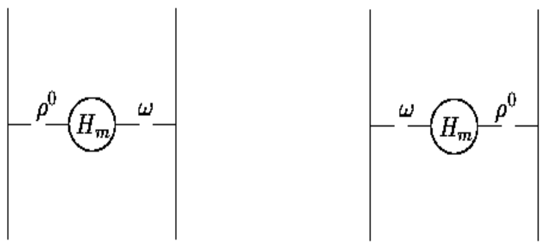
- **E03: X rays from Ξ^- atoms**
- **E05:** $^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$ **textBlue**
- **E07: S=-2 emulsion-counter studies**
- **E10: DCX studies of neutron-rich** $^{A}_{\Lambda}Z$
- **E13:** γ**-ray spectroscopy of** Λ **hypernuclei**
- **E15: search for** K^-pp **in** $^3\mathrm{He}(K^-, n)$
- **E18:** $^{12}_{\Lambda}$**C weak decays**
- **E19: search for** Θ^+ **pentaquark in** $\pi^-p \to K^-X$
- **E22: weak interactions in** $^4_\Lambda\mathrm{H} - {}^4_\Lambda\mathrm{He}$
- **E27: search for** K^-pp **in** $d(\pi^+, K^+)$
- **E31: study of** $\Lambda(1405)$ **by in-flight** $d(K^-, n)$
- **E40: measurement of** Σp **scattering**
- **E42: search for** H**-dibaryon in** (K^-, K^+) **nuclear reactions**
- **E62: precision spectroscopy of X-rays from kaonic atoms with TES**

Charge Symmetry Breaking in Hypernuclei

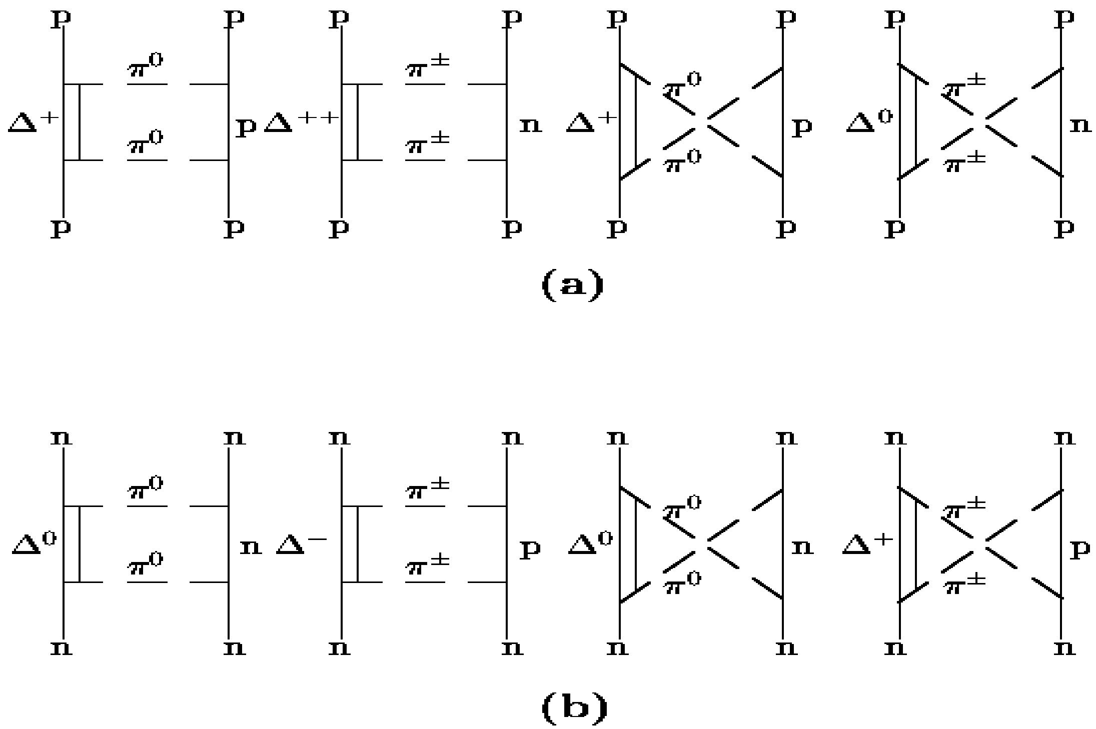
Avraham Gal, Hebrew University, Jerusalem

- **Evidence for CSB & recent exp progress on ($^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He) levels from MAMI & J-PARC.**
- **Dalitz (1964): CSB is driven by Λ-Σ^0 mixing.**
- **Bodmer (1966)...Gibson...Akaishi (2000): $\Lambda(N)$-$\Sigma(N)$ SI coupling in s-shell hypernuclei.**
- **Nogga (2002): 1st realistic 4-body calculation.**
- **Millener (2005): apply $\Lambda\Sigma$ coupling in p-shell.**
- **Linking CSB $\Lambda\Sigma^0$ mixing to SI $\Lambda\Sigma$ coupling in the Akaishi-Millener schematic model. Results for A=4 & p-shell: A. Gal, PLB 744 (2015) 352.**

NN and Nuclear CSB



OBE $\rho^0 - \omega$ mixing



Δ(1232) in TPE: (a) pp (b) nn

R. Machleidt, H. Müther, PRC 63 (2001) 034005

Each mechanism separately reproduces s-wave NN CSB.

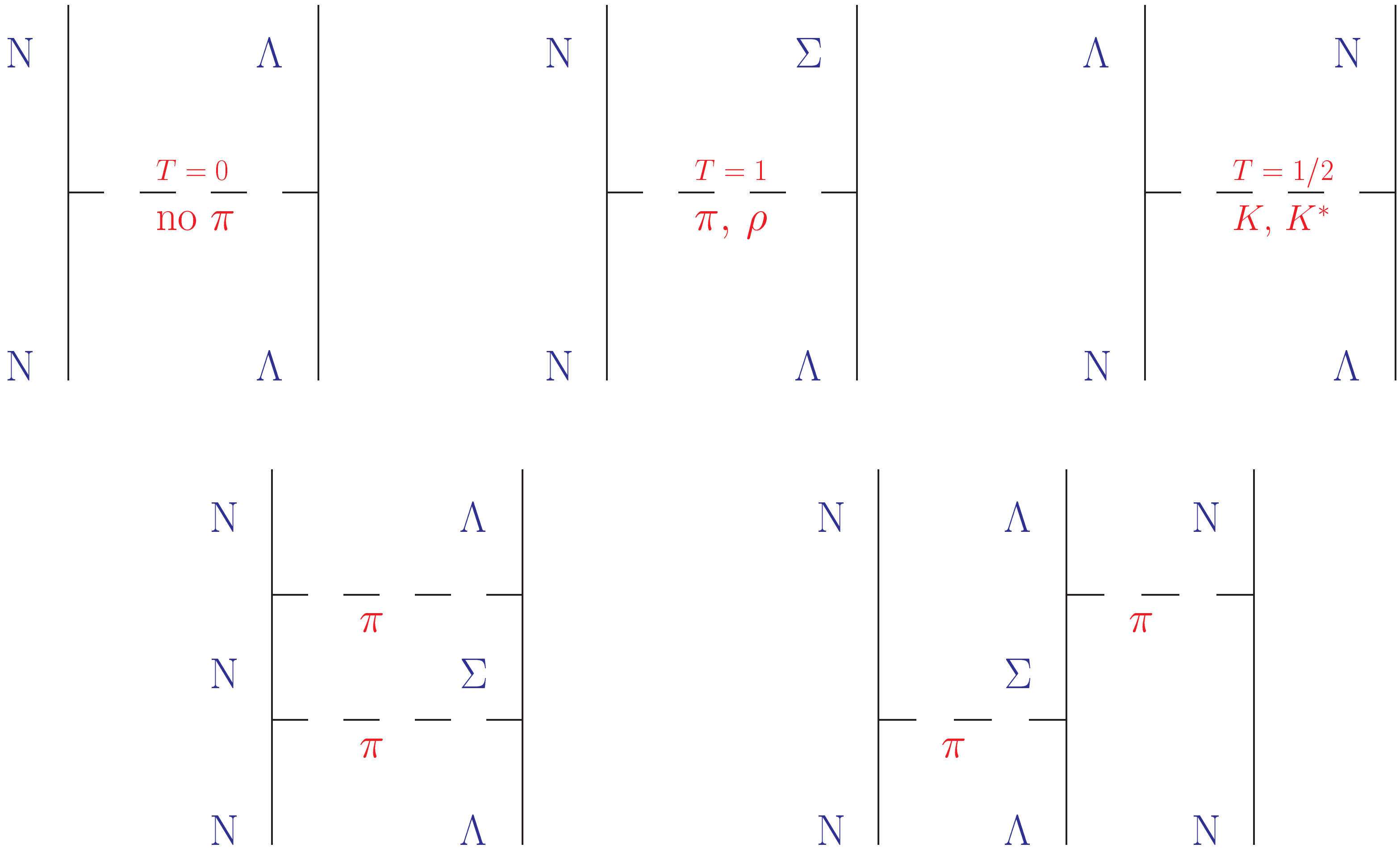
NN and Nuclear CSB continued

	$\rho^0-\omega$	$\Delta(1232)$	AV18	Exp./Emp.
$-a^C_{pp}$ (fm)	7.8154	7.8154	7.8138	7.8149±0.0029
$-a^N_{pp}$ (fm)	17.460	17.460	17.164	–
r^C_{pp} (fm)	2.773	2.773	2.787	2.769±0.014
r^N_{pp} (fm)	2.845	2.845	2.865	–
$-a^N_{nn}$ (fm)	18.968	18.968	18.818	18.9±0.4
r^N_{nn} (fm)	2.816	2.819	2.834	2.75±0.11
$\Delta a_{\rm CSB}$ (fm)	1.508	1.508	1.654	1.6±0.6
$\Delta r_{\rm CSB}$ (fm)	0.029	0.026	0.031	0.10±0.12
^{3}H–^{3}He (keV)	65.8	60.0	65.1	67±9

CSB gives ≈70 keV out of the Coulomb dominated ΔB(^{3}H–^{3}He)=764 keV.

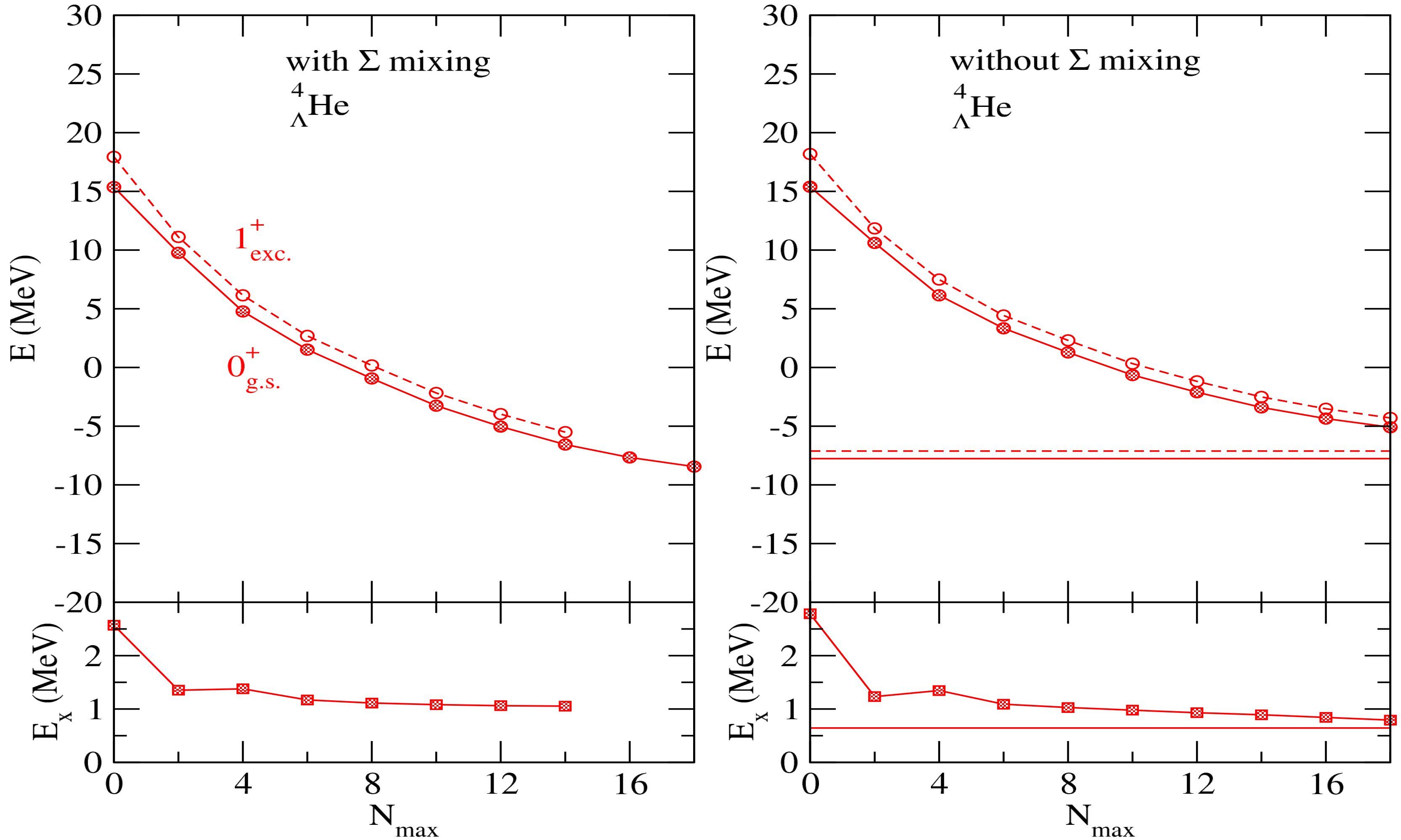
In χEFT add 2 CD contact terms at N3LO [D.R. Entem, R. Machleidt, PRC 68 (2003) 041001(R)].

$S = -1 \quad T = 1/2 \qquad \Lambda N - \Sigma N$



LO χEFT YN model: PS meson exchange + 5 contact terms

[Polinder-Haidenbauer-Meißner, NPA 779, 244 (2006)].



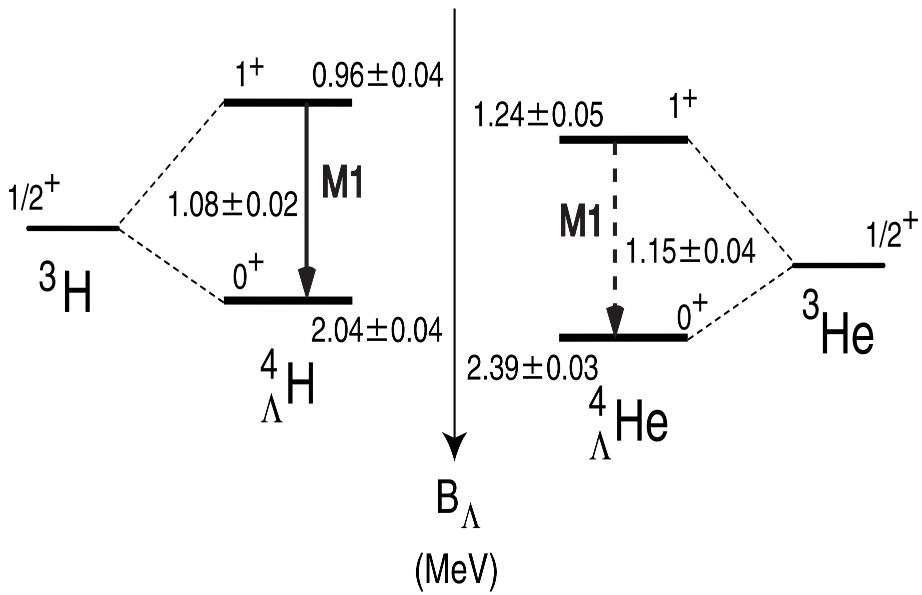
ΛN-ΣN ($\Lambda\Sigma$) coupling provides ≈1/3 of E_x

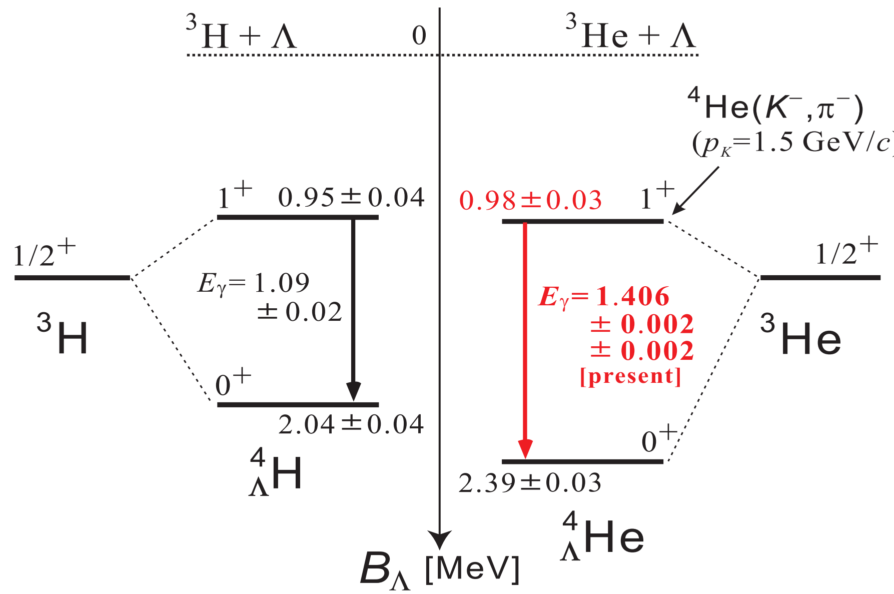
NCSM calculations by Daniel Gazda, presented at HYP2015

D. Gazda et al., FBS 55, 857 (2014) R. Wirth et al., PRL 113, 192502, using LO chiral potentials [H. Polinder et al., NPA 779, 244 (2006)].

$^{4}_{\Lambda}$H–$^{4}_{\Lambda}$He levels before and after J-PARC E13 exp.

T. O. Yamamoto et al., J-PARC-E13, PRL 115 (2015) 222501



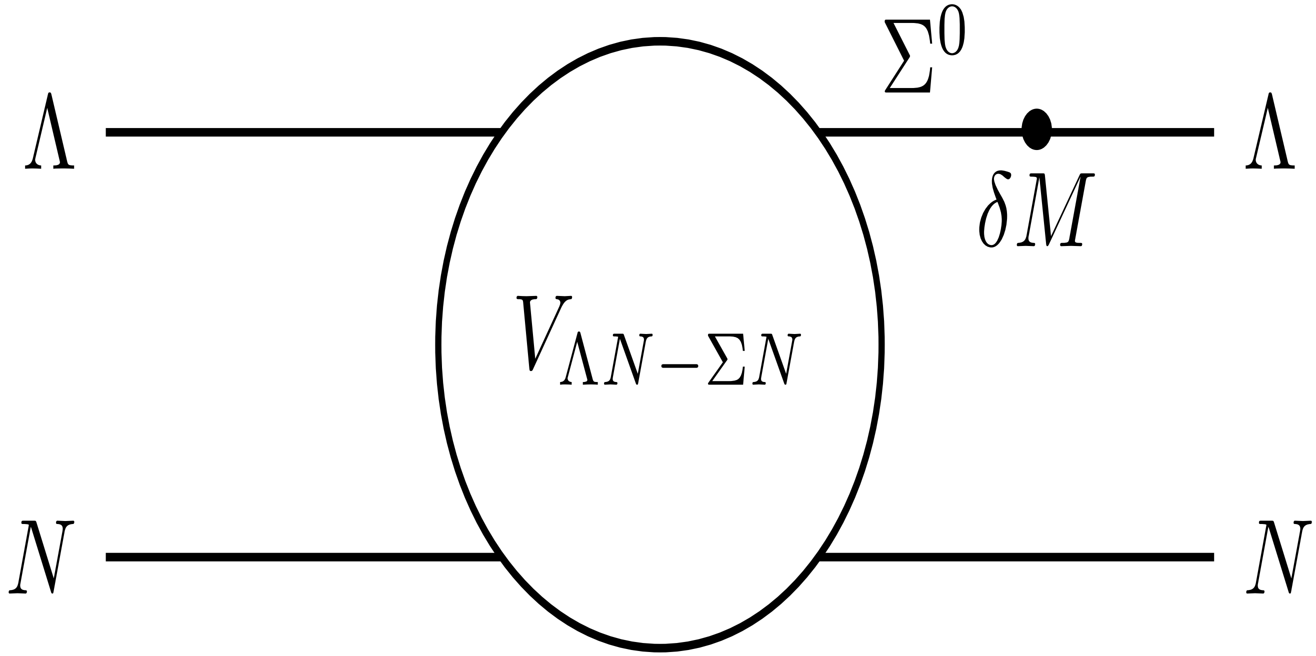


MAMI's new value $B_\Lambda(^{4}_{\Lambda}\mathrm{H})$=2.12±0.01±0.09 MeV, consistent with emulsion value, obtained by measuring decay π^- in $^{4}_{\Lambda}\mathrm{H}\to{}^{4}\mathrm{He}+\pi^-$ [PRL 114 (2015) 232501].

CSB is strongly spin dependent, dominantly in $0^+_{\mathrm{g.s.}}$

350±60 keV in $^{4}_{\Lambda}$H-$^{4}_{\Lambda}$He vs. ≈−70 keV in ^{3}H-^{3}He.

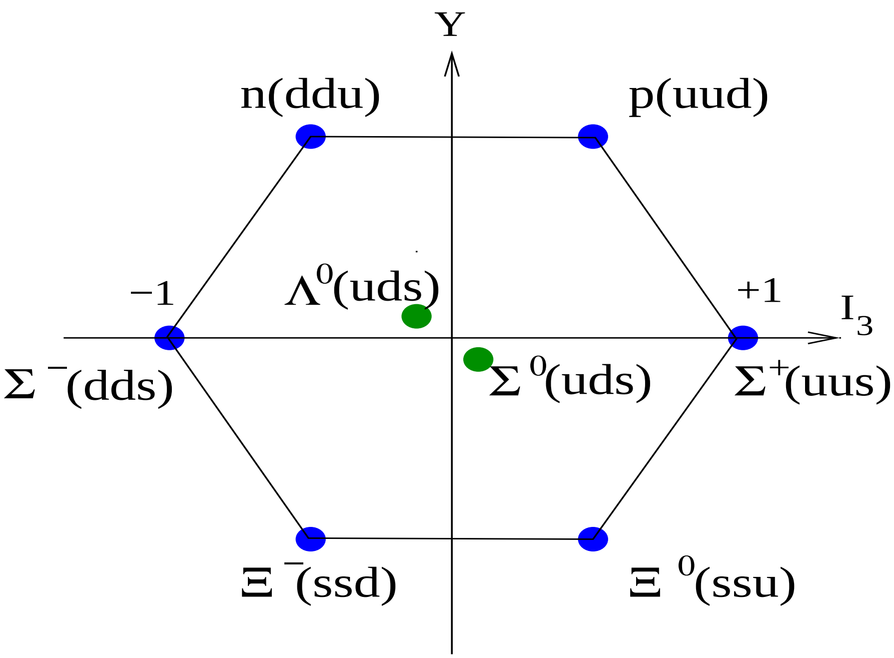
Relating Λ-Σ^0 CSB mixing to $\Lambda\Sigma$ SI coupling

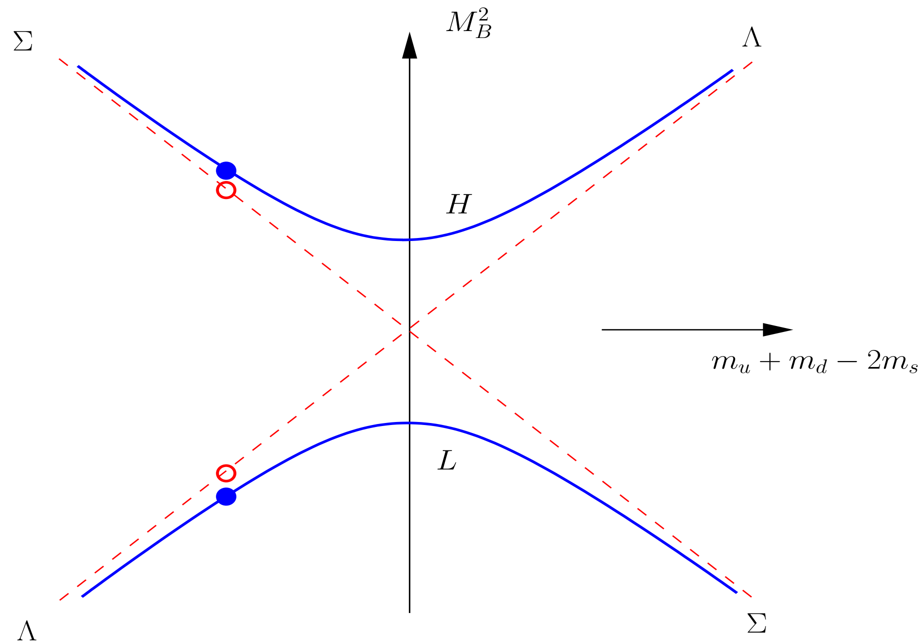


Dalitz-von Hippel (1964): "applies to any isovector meson exchange, π, ρ..." & also to χEFT contact interactions.

Applied systematically by A. Gal, PLB 744 (2015) 352 (also in p-shell) & D. Gazda, A. Gal, arXiv:1512.01049.

CSB main contribution: Λ-Σ^0 mixing





Dalitz–von Hippel, PL 10 (1964) 153:

$\langle\Sigma^0|\delta M|\Lambda\rangle = \frac{1}{\sqrt{3}}[(M_{\Sigma^0} - M_{\Sigma^+}) - (M_n - M_p)]$**=1.14(05) MeV,**

and mixing angle $\tan\alpha = \langle\Sigma^0|\delta M|\Lambda\rangle/(M_{\Sigma^0} - M_\Lambda)$**=0.015(1).**

LQCD gives half of it; see Gal, PRD 92 (2015) 018501.

- **$\Lambda - \Sigma^0$ mixing implies a nonzero $g_{\Lambda\Lambda\pi^0}$**

$$g_{\Lambda\Lambda\pi^0} = -2\,\frac{\langle\Sigma^0|\delta M|\Lambda\rangle}{M_{\Sigma^0}-M_\Lambda} g_{\Lambda\Sigma^0\pi^0} = -0.0297 g_{\Lambda\Sigma^0\pi^0},$$

leading to a ΛN OPE potential $V^{\rm CSB}_{\Lambda N}$(OPE)

$$= -0.0242\,\tau_{Nz}\frac{f^2_{NN\pi}}{4\pi}\frac{m_\pi}{3}[\vec{\sigma}_\Lambda \cdot \vec{\sigma}_N + T(r)S(\hat{r};\, \vec{\sigma}_\Lambda, \vec{\sigma}_N)]Y(r),$$

giving $\geq$100 keV for the A=4 $0^+_{\rm g.s.}$ levels.

- **Other isovector meson exchanges, notably ρ exchange, augment the π's central contribution and cancel largely its tensor contribution.**

- **However, ΣNNN admixtures to ΛNNN require a dynamical treatment, perhaps abused by going too soon to use $V^{\rm CSB}_{\Lambda N}$(OPE). CSB and SI are linked for $I_{NY} = 1/2$ matrix elements by**

$$\langle N\Lambda|V^{\rm CSB}_{\Lambda N}|N\Lambda\rangle = -0.0297\,\tau_{Nz}\,\frac{1}{\sqrt{3}}\,\langle N\Sigma|V^{\rm SI}|N\Lambda\rangle.$$

Recent NCSM calculations

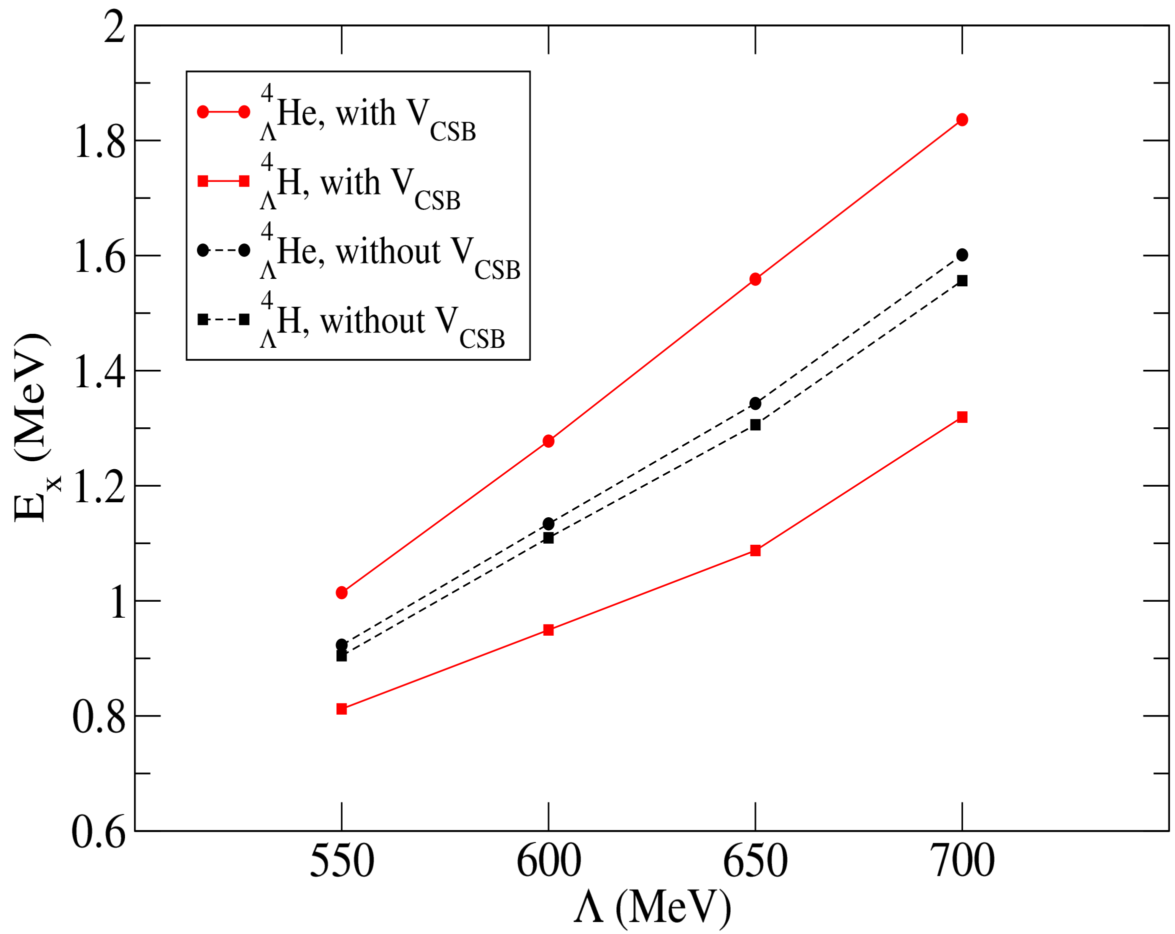
- **No-Core Shell-Model (NCSM) 4-body calculation in a translationally invariant Jacobi-coordinate harmonic oscillator (HO) basis, antisymmetrized for nucleons.**
- **χEFT interactions: N3LO NN & N2LO NNN, LO YN (Bonn-Jülich) with CSB introduced by relating Λ–Σ^0 mixing to ΛN–ΣN strong-interaction coupling.**
- **Diagonalize Hamiltonian in finite four-body HO bases, admitting all HO excitation energies N$\hbar\omega$, N$\leq$N$_{\mathrm{max}}$. Extrapolated energy values E(ω), N$_{\mathrm{max}}\to\infty$, obtained by fitting an exponential function to E(N$_{\mathrm{max}}$, ω fixed) sequences in the vicinity of the variational minima with respect to ω. Gazda-Gal, arXiv:1512.01049.**

Ab-initio ${}^{4}_{\Lambda}$He NCSM calculations with χEFT YN interactions

LO/NLO	cutoff	550	600	650	700	Exp. (MeV)
LO	$B_{\Lambda}^{J=0}({}^{4}_{\Lambda}\mathrm{He})$	2.586	2.444	2.365	2.423	2.39±0.03
LO	$B_{\Lambda}^{J=1}({}^{4}_{\Lambda}\mathrm{He})$	1.572	1.166	0.683	0.482	0.98±0.03
LO	$E_{\mathrm{x}}({}^{4}_{\Lambda}\mathrm{He})$	1.014	1.278	1.682	1.941	1.406±0.003
NLO	$E_{\mathrm{x}}(\mathrm{CS})$	0.67	0.75	0.69	0.71	CS: ≈1.25

LO: Gazda-Gal, NLO: A. Nogga, NPA 914 (2013) 140

- N3LO NN + N2LO NNN + LO/NLO YN.
- ΛN-ΣN coupling introduced explicitly.
- LO: Relative Jacobi coordinates in HO basis.
- NLO: Faddeev Yakubovsky; $\mathrm{E_x(NLO)} \ll \mathrm{E_x(exp)}$.

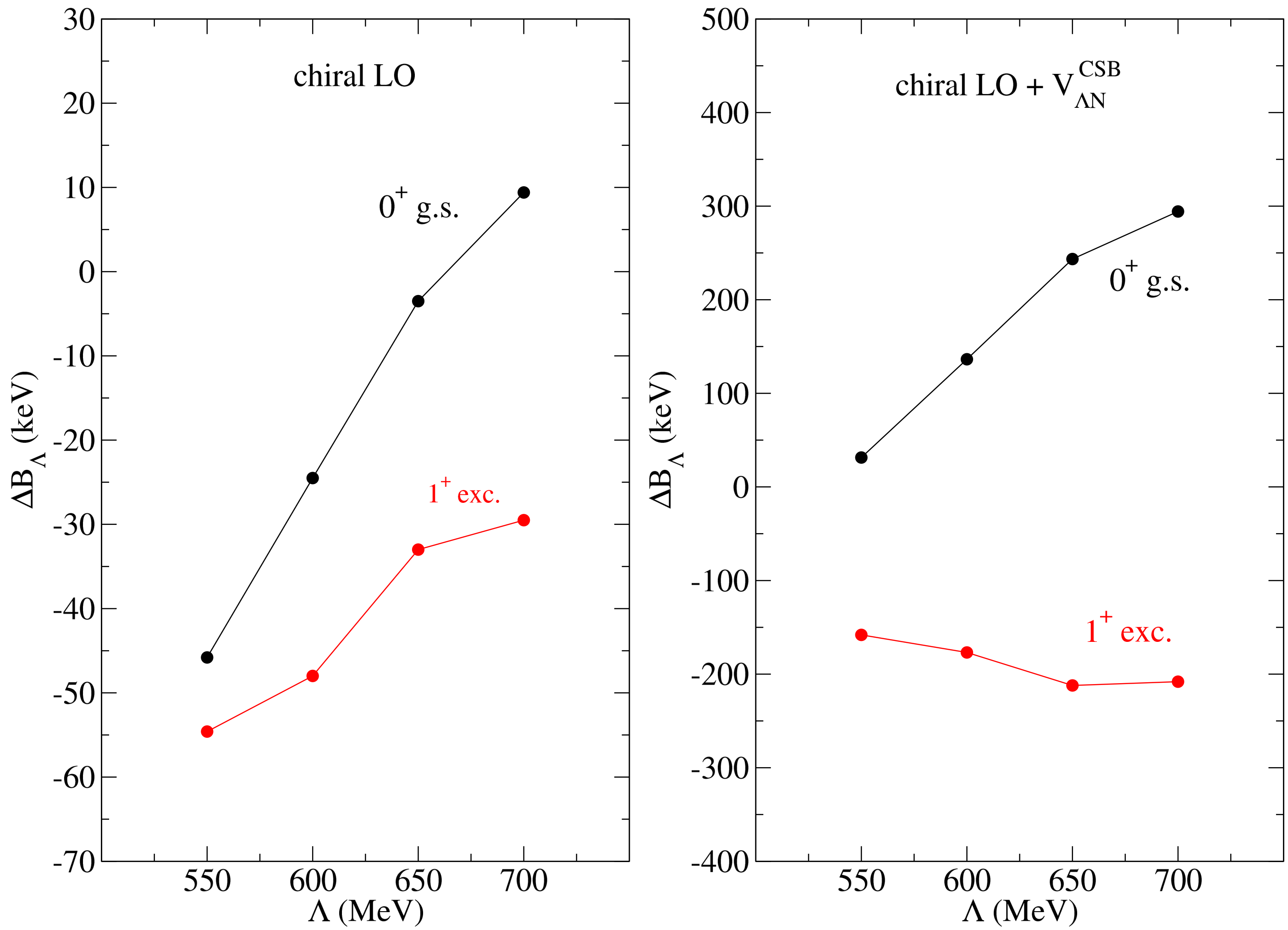


D. Gazda, A. Gal, arXiv:1512.01049

EFT LO cutoff momentum (Λ) dependence of $E_x(0^+ \rightarrow 1^+)$ at HO $\hbar\omega$=30,32 MeV. [exp: $E_x(^4_\Lambda He)$=1.41±0.02 MeV]

CSB Λ-Σ^0 mixing is correlated with SI ΛΣ coupling.

Λ=600 MeV: ΔE_x=0.33±0.03 MeV [exp: 0.32±0.02 MeV]

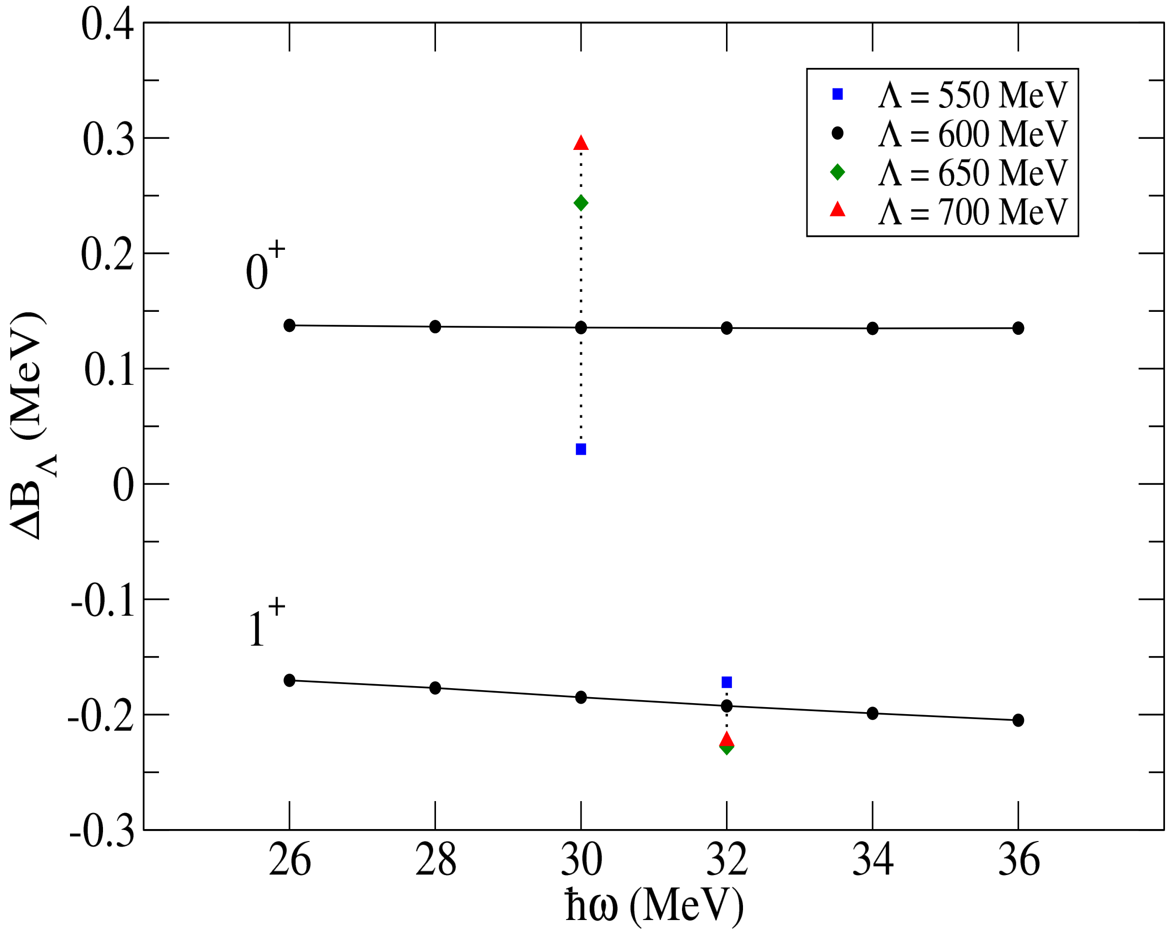


A=4 CSB: D. Gazda, A. Gal, arXiv:1512.01049

$B_\Lambda(0^+) \approx$ cutoff-independent (dispersion $\sim$100 keV)

$B_\Lambda(1^+)$ is cutoff-dependent (dispersion $\sim$0.5 MeV)

but $\Delta B_\Lambda(0^+ \; 1^+)$ cutoff $-$ (in) dependent.



HO $\hbar\omega$ dependence of $\Delta B_\Lambda({}^4_\Lambda\mathrm{He}–{}^4_\Lambda\mathrm{H})$ for 0^+ & 1^+.
Note $\pm$ sign pattern resulting from ${}^1S_0$ Λ-Σ contact term dominance at LO [Polinder-Haidenbauer-Meißner 2006].
Λ=600 MeV: $\Delta(\Delta B_\Lambda)$=0.33±0.03 MeV [exp 0.32±0.02 MeV]

Other CSB calculations

in the s- & p-shell

CSB contributions (keV) in A=4 hypernuclei in several model calculations

${}^4_\Lambda$He–${}^4_\Lambda$H	$P_\Sigma(\%)$	ΔT_{YN}	ΔV_C	ΔV_{YN}	ΔB^4_Λ	ΔB^4_Λ
model	$0^+_{\rm g.s.}$	$0^+_{\rm g.s.}$	$0^+_{\rm g.s.}$	$0^+_{\rm g.s.}$	$0^+_{\rm g.s.}$	$1^+_{\rm exc}$
ΛNNN [CHCG]	–	–	-42	91	49	-61
NSC97$_{\rm e}$ [NKG]	1.6	47	-16	44	75	-10
NSC97$_{\rm f}$ [HMNP]	1.8				100	-10
NLO chiral [N]	2.1	55	-9	–	46	
$(\Lambda\Sigma)_{\rm e}$ [G]	0.72	39	-45	232	226	30
$(\Lambda\Sigma)_{\rm f}$ [G]	0.92	49	-46	263	266	39

Coon, Han, Carlson, Gibson, arXiv:nucl-th/9903034.

Nogga, Kamada, Glöckle, PRL 88 (2002) 172501.

Haidenbauer, Meißner, Nogga, Polinder, LNP 724 (2007) 113.

Nogga, NPA 914 (2013) 140. **Gal, PLB 744 (2015) 352.**

Compare to CSB in observed $1^+ \to 0^+$ γ ray energies:

$\Delta \mathbf{E}_{\rm x} = \Delta(\Delta \mathbf{B}_\Lambda) \equiv \Delta B_\Lambda(0^+) - \Delta B_\Lambda(1^+)$ **$\leq$110, $\approx$210, $\approx$320 keV.**

p-shell CSB contributions in $(\Lambda\Sigma)_e$ coupling model

${}^{A}_{\Lambda}Z_{>}$–${}^{A}_{\Lambda}Z_{<}$ pairs	I_C, J^{π}_C	P_{Σ} (%)	ΔT_{YN} (keV)	ΔV_C (keV)	ΔV_{YN} (keV)	$\Delta B^{\rm calc}_{\Lambda}$ (keV)	$\Delta B^{\rm exp}_{\Lambda}$ [D] (keV)
${}^{4}_{\Lambda}$He–${}^{4}_{\Lambda}$H	$\frac{1}{2}, 0^+$	0.72	39	−45	232	226	+350±60
${}^{7}_{\Lambda}$Be–${}^{7}_{\Lambda}$Li*	$1, \frac{1}{2}^+$	0.12	3	−70 [HYMK]	50	−17	−100±90
${}^{8}_{\Lambda}$Be–${}^{8}_{\Lambda}$Li	$\frac{1}{2}, 1^-$	0.20	11	−81 [HKMYY]	119	+49	+40±60
${}^{9}_{\Lambda}$B–${}^{9}_{\Lambda}$Li	$1, \frac{3}{2}^+$	0.23	10	−145 [M]	81	−54	−210±220
${}^{10}_{\Lambda}$B–${}^{10}_{\Lambda}$Be	$\frac{1}{2}, 1^-$	0.053	3	−156 [M]	17	−136	−220±250

Davis, NPA 754 (2005) 3c. Millener, unpublished (2015).

Hiyama Yamamoto Motoba Kamimura PRC 80 (2009) 054321.

Hiyama Kamimura Motoba Yamada Yamamoto, PRC 66 (2002) 024007.

Negligible ΔT_{YN} no longer cancels ΔV_C. ΔV_{YN} is smaller than in s shell and, except for A=8, is dominated by the larger-size negative ΔV_C, so CSB becomes negative in the p shell as suggested by the data. However, $B_{\Lambda}({}^{7}_{\Lambda}\text{He})$ is missed by 1-2 σ.

Summary and Outlook

- **CSB is particularly strong in Λ hypernuclei owing to no OPE in a single-channel ΛN SI description. $\Lambda\Sigma$ coupling brings in OPE and relates CSB to SI.**
- **The A=4 hypernuclei, with two bound states each, offer a good test-ground for CSB, highlighted by the γ rays constraint $E_x({}^4_\Lambda He)-E_x({}^4_\Lambda H)\approx 320$ keV.**
- **$E_x({}^4_\Lambda He)-E_x({}^4_\Lambda H)\simeq 100$ keV for SI-acceptable NSC97. $E_x({}^4_\Lambda He)-E_x({}^4_\Lambda H)\approx 300$ keV for LO EFT with cut-off 600 MeV/c, but the cut-off dependence is appreciable owing to exchanges beyond OPE, simulated by zero-range contact interactions.**

(Gazda-Gal, arXiv:1512.01049)

- **The Akaishi-Millener $\Lambda\Sigma$ schematic model produces $\Delta B_\Lambda(0^+)-\Delta B_\Lambda(1^+) = E_x({}^4_\Lambda He)-E_x({}^4_\Lambda H) \approx 200$ keV. Can it be readjusted to get $\approx$300 keV?**

- **The Akaishi-Millener $\Lambda\Sigma$ schematic model explains the CSB sign reversal in the p shell. The CSB magnitude is poorly constrained by the old emulsion values known for a few p-shell isomultiplets. Can any of these be remeasured systematically in a modern facility?**

- **The recently determined $B_\Lambda({}^7_\Lambda He)$ cannot be related by CSB to the emulsion-based B_Λ values of ${}^7_\Lambda Li$ and ${}^7_\Lambda Be$.**

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