Progress & issues in Strangeness NP

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- $\mathcal{S} = -1$: 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?
  $\Theta^+(1530)$ traces in K^+ nuclear dynamics?
- SNP Special Issue: Nucl. Phys. A 881 (2012)
  Proc. HYP 2012: Nucl. Phys. A 914 (2013)

Λ hypernuclear dynamics

Studies of Λ hypernuclei

- (K^-, π^-) – **emulsions, CERN, BNL, KEK, LNF, J-PARC**
- (π^+, K^+) – **BNL, KEK, J-PARC**
- $(\pi^+, K^+\gamma)$ – **KEK &** $(K^-, \pi^-\gamma)$ – **BNL, J-PARC with Hyperball-J**
- $(e, e' K^+)$ – **JLab, Hall A and Hall C; now also at MAMI**
- **DCX:** (π^-, K^+) – **KEK, J-PARC &** $(K^-_{\rm stop}, \pi^+_{\rm prod}\, \pi^-_{\rm decay})$ – **LNF**

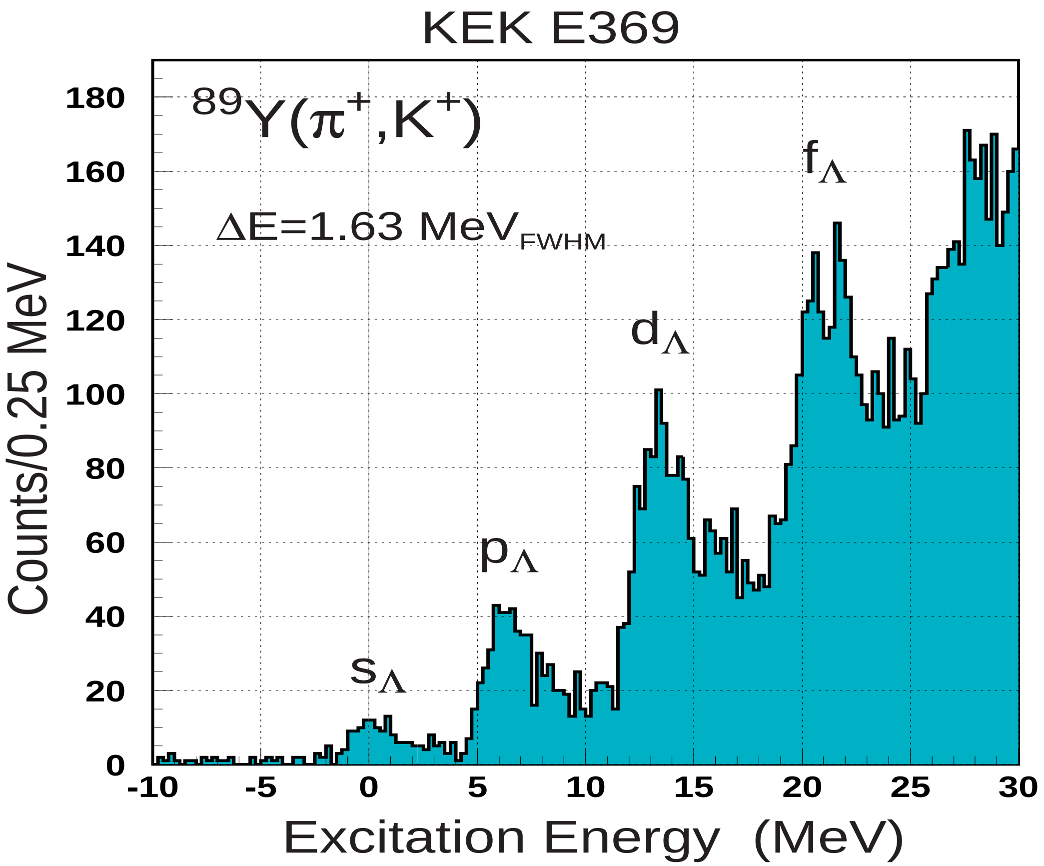
Scheduled experiments at J-PARC using meson beams:

- **E13:** γ**-ray spectroscopy of** Λ **hypernuclei**
- **E10: DCX studies of neutron-rich** ${}^{A}_{\Lambda}Z$ **(**^{6}Li, ^{9}Be **&** ^{10}B **targets)**
- **E18:** ${}^{12}_{\Lambda}$C **weak decays**
- **E22: weak interactions in** ${}^{4}_{\Lambda}$H – ${}^{4}_{\Lambda}$He

Studies of exotica & light hypernuclei lifetimes by heavy ions:

- **In GSI, the HypHI Experiment,** ^{6}**Li on C at 2** A **GeV**
- **In LHC, the ALICE Collaboration, Pb-Pb at** $\sqrt{s_{NN}}$**=2.76 TeV**

Observation of Λ single-particle states

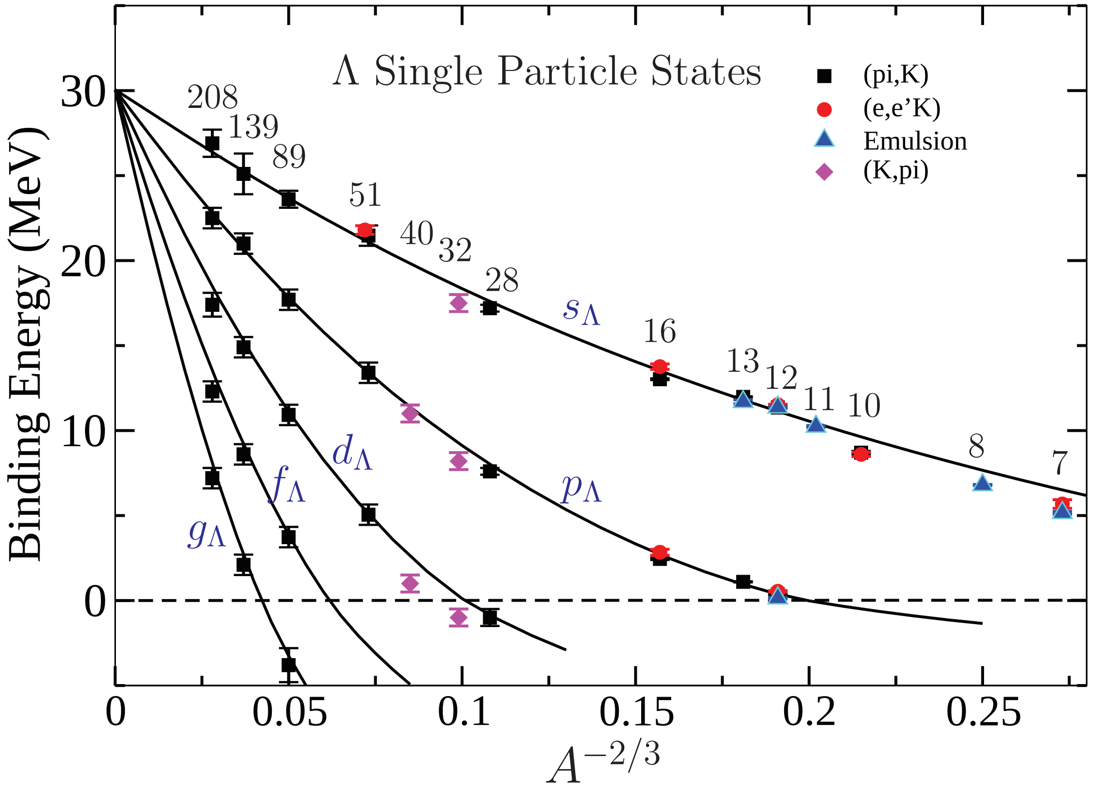


H. Hotchi et al., Phys. Rev. C 64 (2001) 044302 $B_\Lambda = 23.11 \pm 0.10$ MeV

T. Motoba, D.E. Lanskoy, D.J. Millener, Y. Yamamoto, NPA 804 (2008) 99:

negligible Λ spin-orbit splittings, 0.2 MeV for $1f_\Lambda$

Update: Millener, Dover, Gal PRC 38, 2700 (1988)

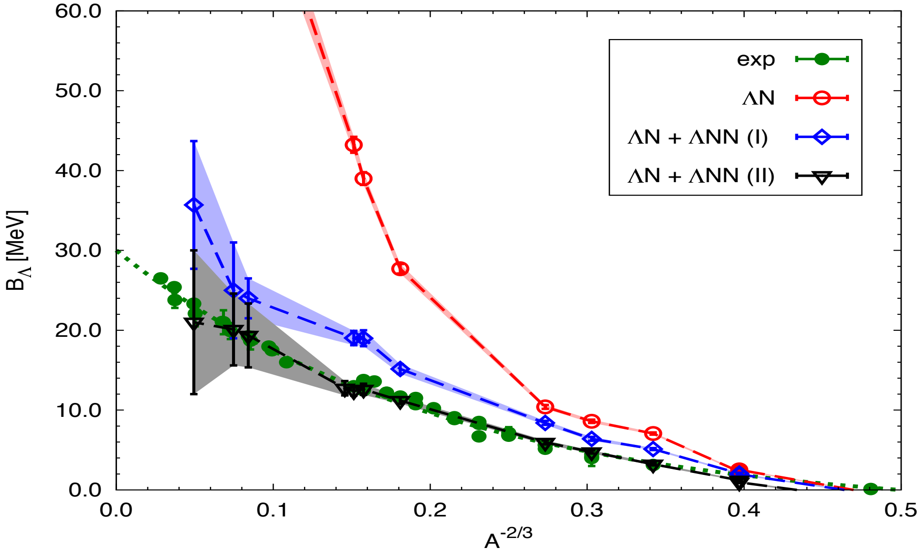


Woods-Saxon $V = 30.05$ MeV, $r = 1.165$ fm, $a = 0.6$ fm

Textbook example of shell model at work.

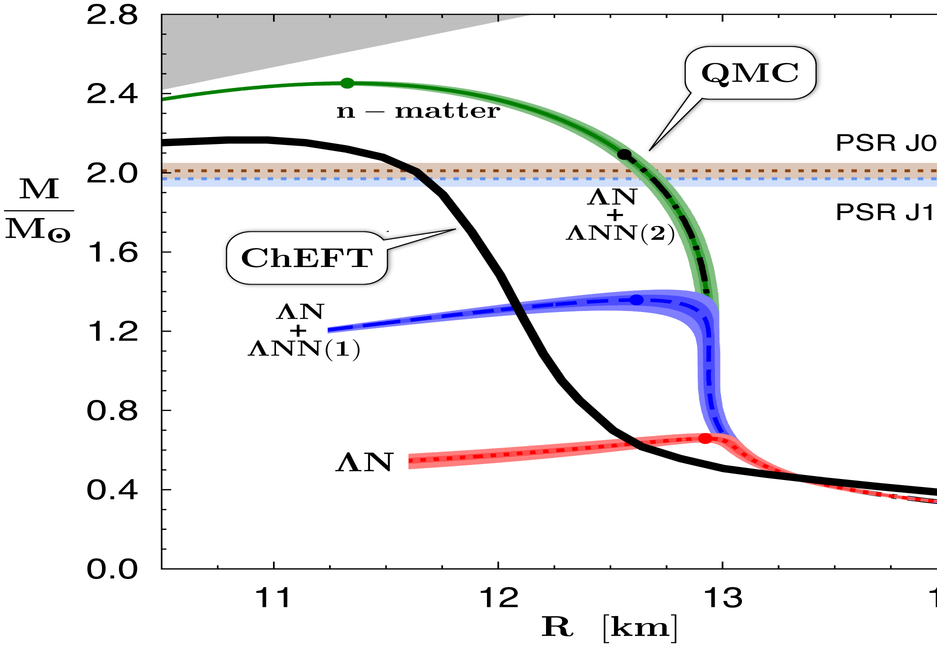
SHF studies suggest ΛNN repulsion.

Hyperon puzzle: QMC calculations



Lonardoni et al, PRC 89 (2014) 014314

ΛNN effect on B_Λ(g.s.)

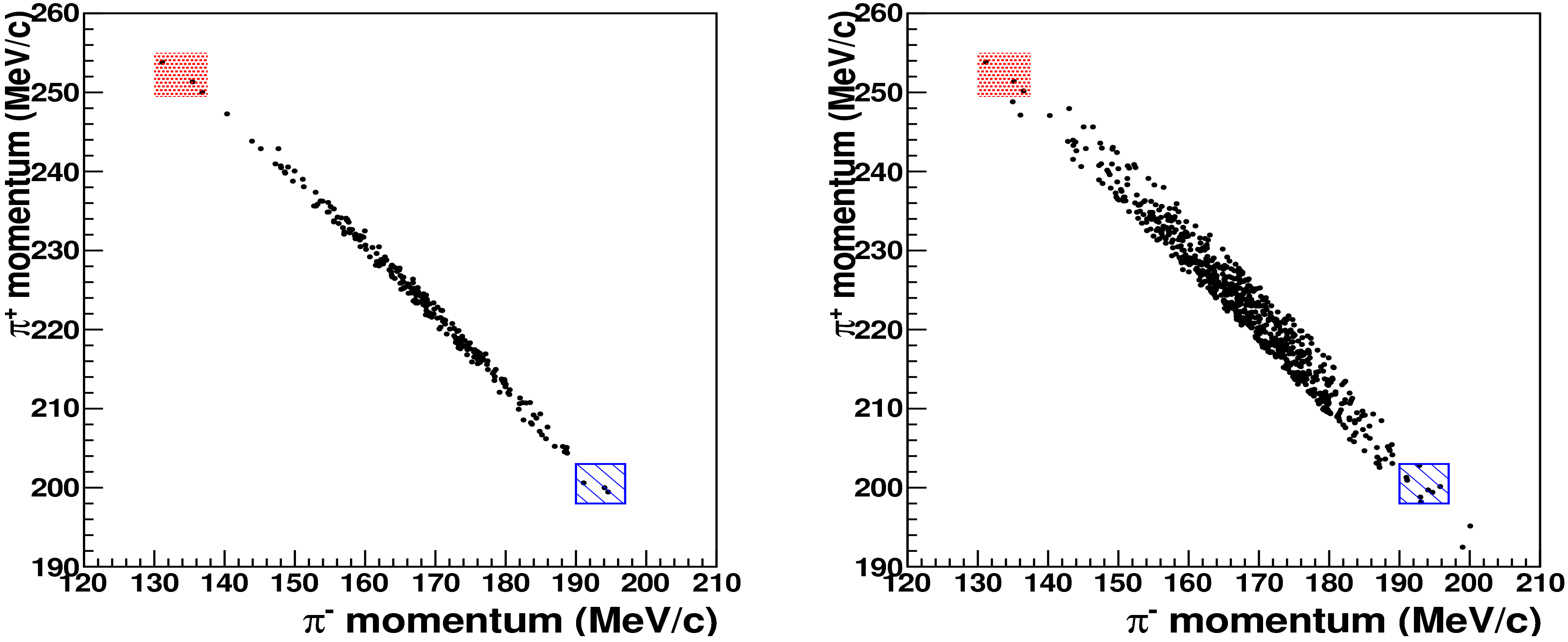


PRL 114 (2015) 092301

ΛNN effect on neutron stars

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

FINUDA: p_{π^+} **vs.** p_{π^-} **in** $^6\mathbf{Li}(K^-_{\rm stop},\pi^+)^6_\Lambda\mathbf{H}$, $^6_\Lambda\mathrm{H}\to{}^6\mathrm{He}+\pi^-$



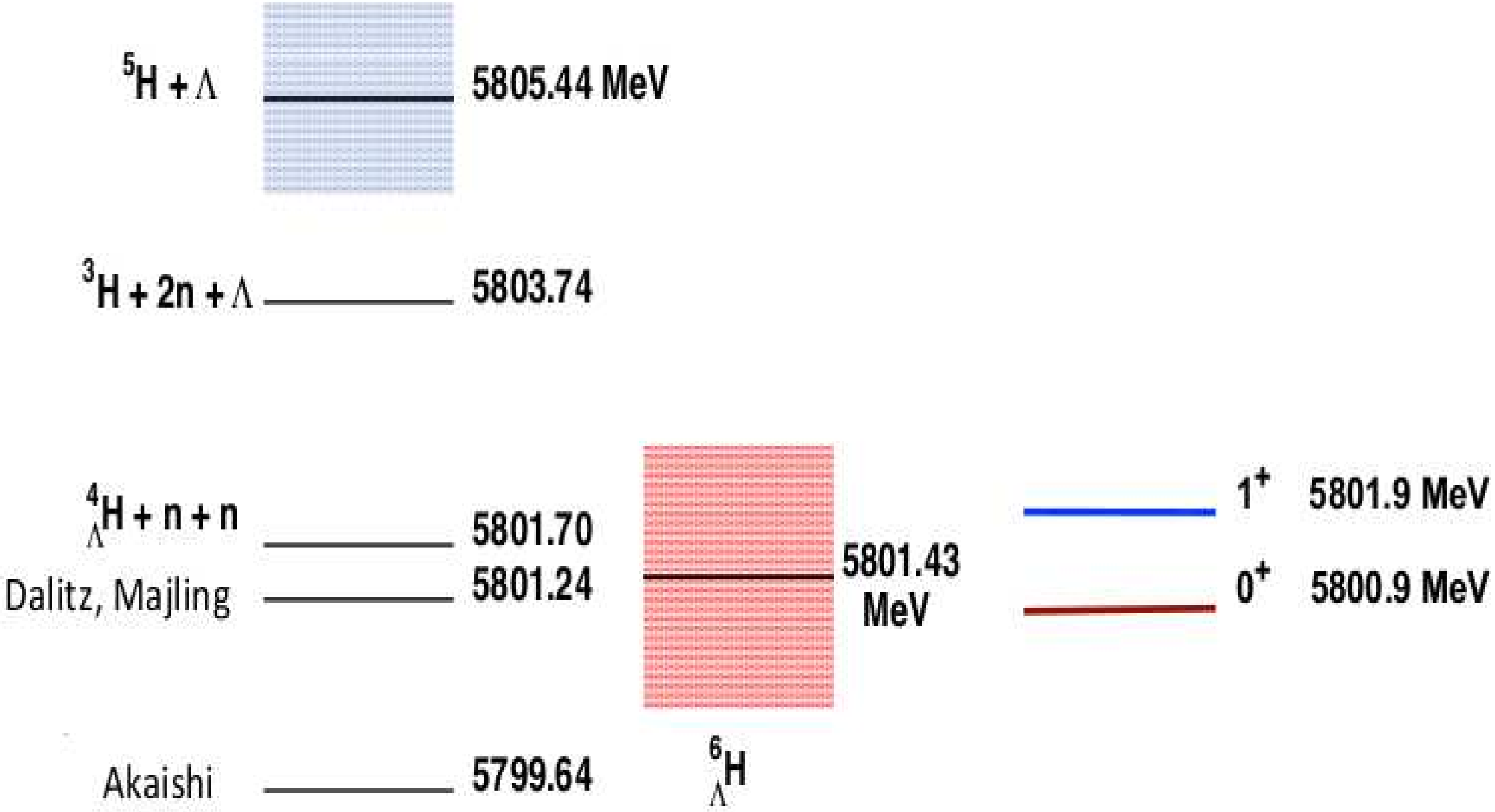
$T(\pi^+)+T(\pi^-)$=202–204 MeV (l.h.s.) 200–206 MeV (r.h.s.)

Red rectangles: p_{π^+}=250–255, p_{π^-}=130–137 MeV/c.

The 3 events in red are stable against $T(\pi^+)+T(\pi^-)$ cuts.

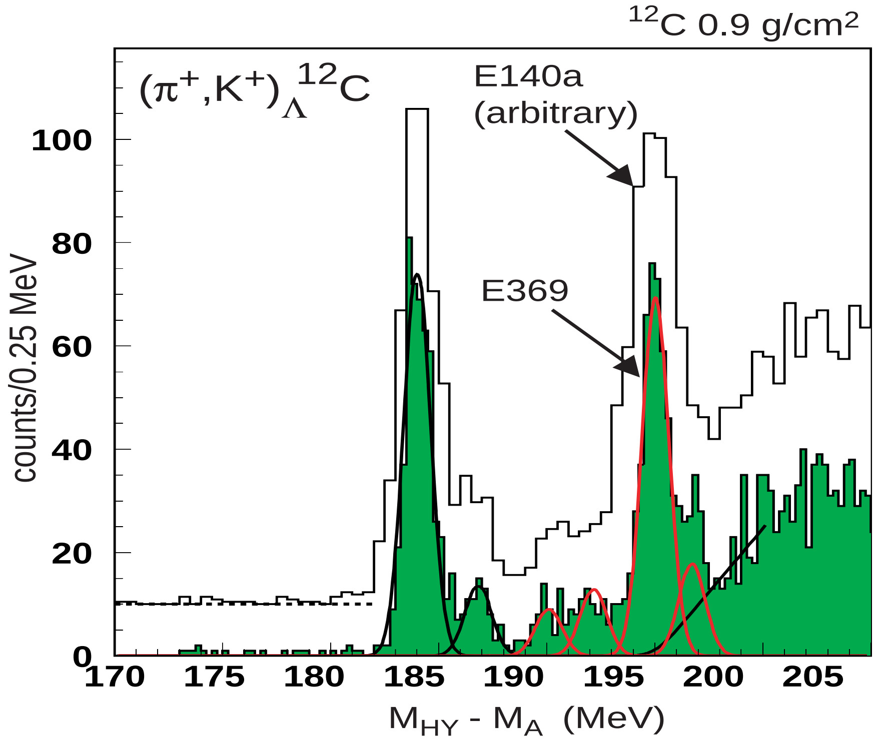
$^6_\Lambda$H not confirmed in (π^-,K^+) by J-PARC E10.

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



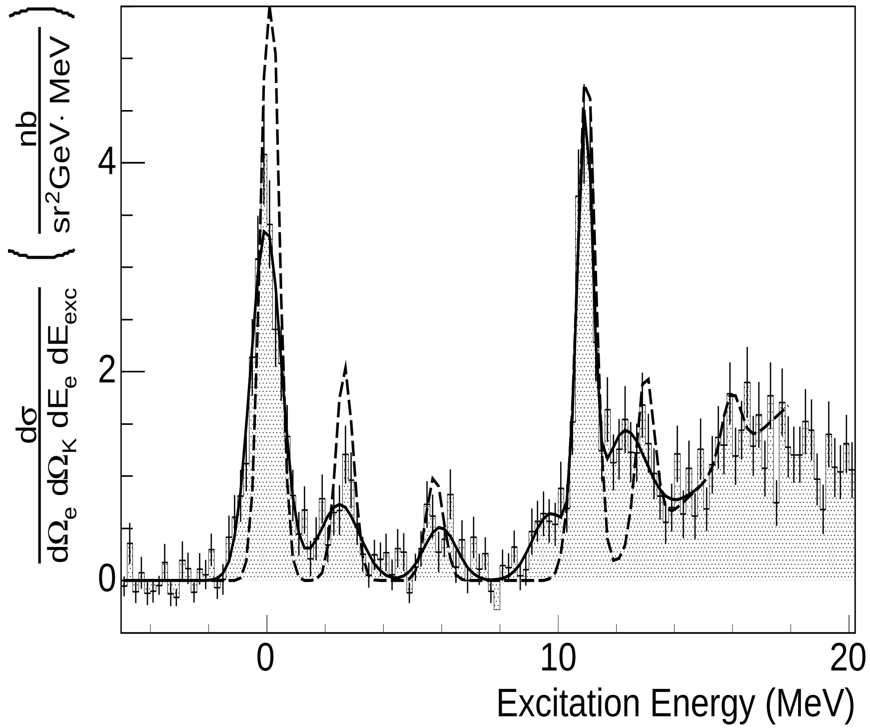
- **Three $^6_\Lambda$H candidate events out of 2.7 x 10^7 $K^-_{\rm stop}$.**
- **$B_\Lambda(^6_\Lambda$H) constrains $\Lambda N \leftrightarrow \Sigma N$ effects in neutron-rich $^A_\Lambda Z$.**

Room for hypernuclear spectroscopy



H. Hotchi et al., PRC 64 (2001) 044302

$1s_\Lambda - 1p_\Lambda$ intermediate structure

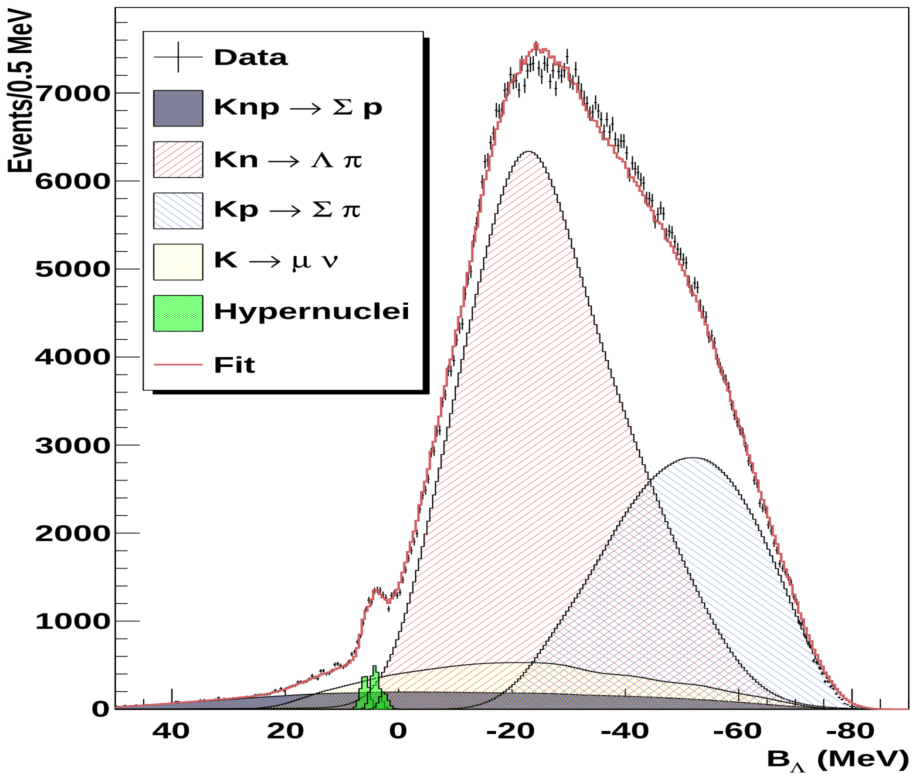


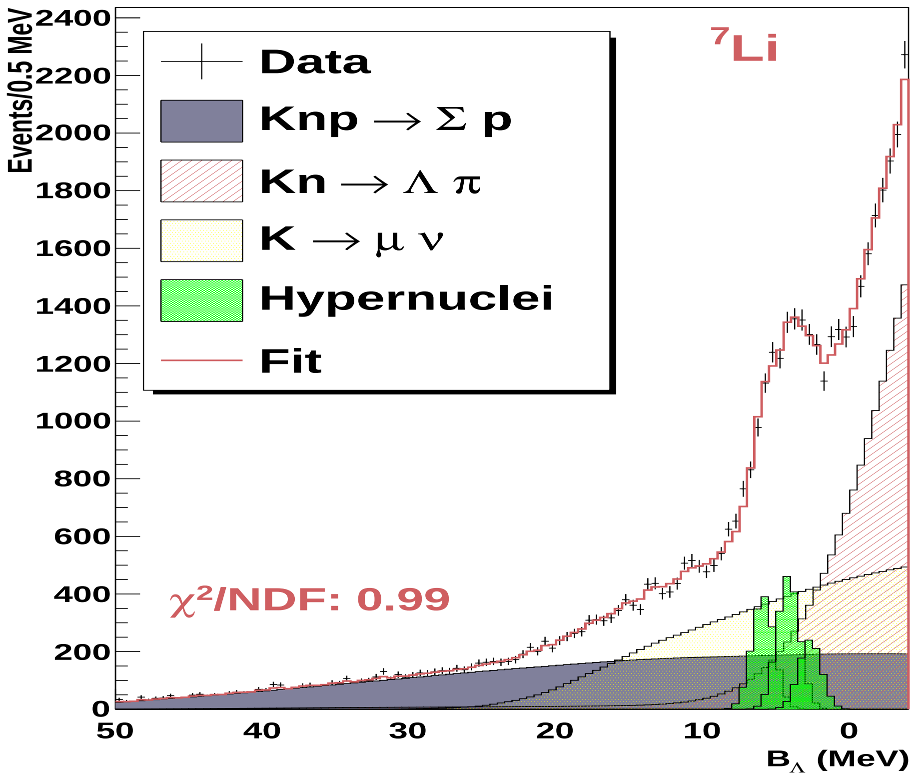
M. Iodice et al., PRL 99 (2007) 052501

$^{12}_{\Lambda}$B in $(e, e'K^+)$, Jlab Hall A

energy resolution 1.6 MeV → 0.6 MeV [PRC 90 (2014) 034320]

Hypernuclear production in $(K^-_{\rm stop}, \pi^-)$, PLB 698 (2011) 219 & 226





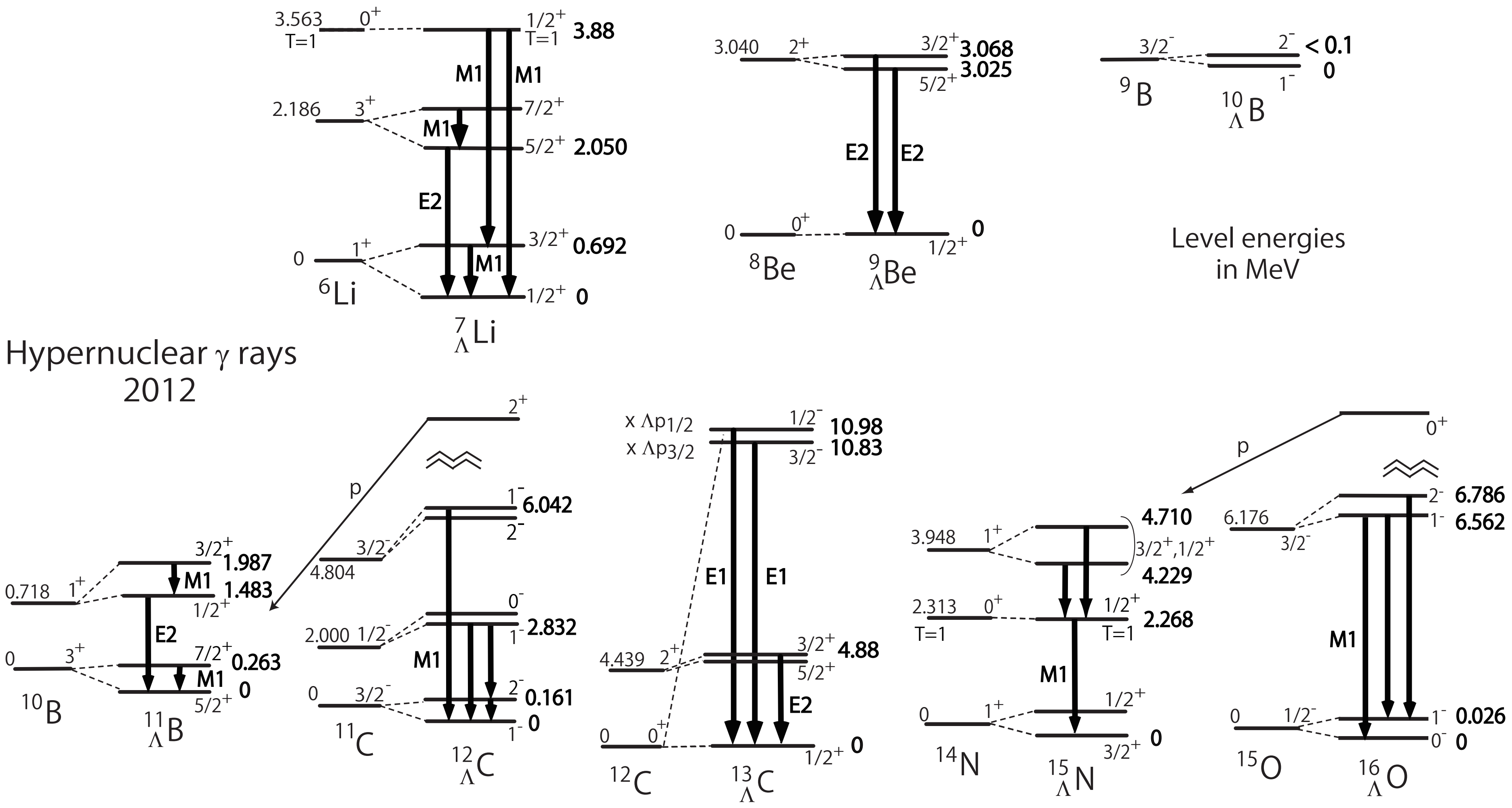
Production spectrum on ^{7}Li

FINUDA, DAΦNE, Frascati

Three $^{7}_{\Lambda}$Li levels, δB_Λ=0.4 MeV

Formation rate $1 \cdot 10^{-3}/K^-_{\rm stop}$

A=7–16 data also indicate DEEP K⁻ nuclear potential.



Hypernuclear level schemes from γ-ray measurements (BNL, KEK)

H. Tamura et al., Nucl. Phys. A 835 (2010) 3 [HYP09], updated at HYP12

Λ spin-orbit splitting: 150 keV in $^{13}_{\Lambda}$C & related 43 keV in $^{9}_{\Lambda}$Be

p-shell Λ hypernuclei

$$V_{\Lambda N} = V_0(r) + V_\sigma(r)\, s_N \cdot s_\Lambda + V_{LS}(r)\, l_{N\Lambda} \cdot (s_\Lambda + s_N) + V_{ALS}(r)\, l_{N\Lambda} \cdot (s_\Lambda - s_N) + V_T(r)\, S_{12}$$

For $p_N s_Y$: $$V_{\Lambda N} = \bar{V} + \Delta\, s_N \cdot s_\Lambda + S_\Lambda\, l_N \cdot s_\Lambda + S_N\, l_N \cdot s_N + T\, S_{12}$$

R.H Dalitz, A. Gal, Ann. Phys. 116 (1978) 167

D.J. Millener, A. Gal, C.B. Dover, R.H. Dalitz, PRC 31 (1985) 499

$N\Lambda$-$N\Lambda$	$\bar{V}$	Δ	S_Λ	S_N	T	from
$A = 7 - 9$	(-1.32)	0.430	-0.015	-0.390	0.030	fit
$A = 11 - 16$	(-1.32)	0.330	-0.015	-0.350	0.024	fit
$N\Lambda$-$N\Sigma$	1.45	3.04	-0.085	-0.085	0.157	input

(in MeV) **D.J. Millener, Nucl. Phys. A 804 (2008) 84**

Doublet spacings in p-shell hypernuclei (in keV)

D.J. Millener, NPA 881 (2012) 298

	J_u^π	J_l^π	$\Lambda\Sigma$	Δ	S_Λ	S_N	T	ΔE^{th}	ΔE^{exp}
${}^{7}_{\Lambda}\mathrm{Li}$	$3/2^+$	$1/2^+$	72	628	-1	-4	-9	693	692
${}^{7}_{\Lambda}\mathrm{Li}$	$7/2^+$	$5/2^+$	74	557	-32	-8	-71	494	471
${}^{8}_{\Lambda}\mathrm{Li}$	2^-	1^-	151	396	-14	-16	-24	450	(442)
${}^{9}_{\Lambda}\mathrm{Be}$	$3/2^+$	$5/2^+$	-8	-14	37	0	28	44	43
${}^{11}_{\Lambda}\mathrm{B}$	$7/2^+$	$5/2^+$	56	339	-37	-10	-80	267	264
${}^{11}_{\Lambda}\mathrm{B}$	$3/2^+$	$1/2^+$	61	424	-3	-44	-10	475	505
${}^{12}_{\Lambda}\mathrm{C}$	2^-	1^-	61	175	-22	-13	-42	153	161
${}^{15}_{\Lambda}\mathrm{N}$	$3/2_2^+$	$1/2_2^+$	65	451	-2	-16	-10	507	481
${}^{16}_{\Lambda}\mathrm{O}$	1^-	0^-	-33	-123	-20	1	188	23	26
${}^{16}_{\Lambda}\mathrm{O}$	2^-	1_2^-	92	207	-21	1	-41	248	224

$\Lambda\Sigma$ coupling contributions normally are below 100 keV

The lightest, s-shell, Λ hypernuclei

${}^{A}_{\Lambda}$Z	T	$J^{\pi}_{\text{g.s.}}$	B_{Λ} (MeV)	$J^{\pi}_{\text{exc.}}$	E_x (MeV)
${}^{3}_{\Lambda}$H	0	$1/2^+$	0.13(5)		
${}^{4}_{\Lambda}$H–${}^{4}_{\Lambda}$He	1/2	0^+	2.04(4)–2.39(3)	1^+	1.09(2)–1.406(3)
${}^{5}_{\Lambda}$He	0	$1/2^+$	3.12(2)		

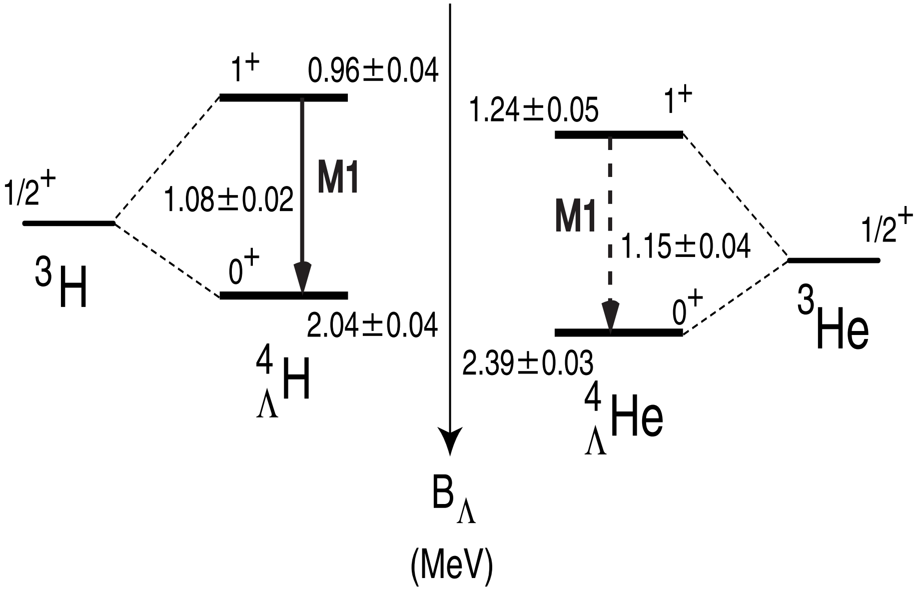
- **No ΛN and no Λnn bound state are expected.**
- **$\Delta B_{\Lambda}({}^{4}_{\Lambda}\text{He}–{}^{4}_{\Lambda}\text{H})=0.35(5)$ MeV: very large CSB.**

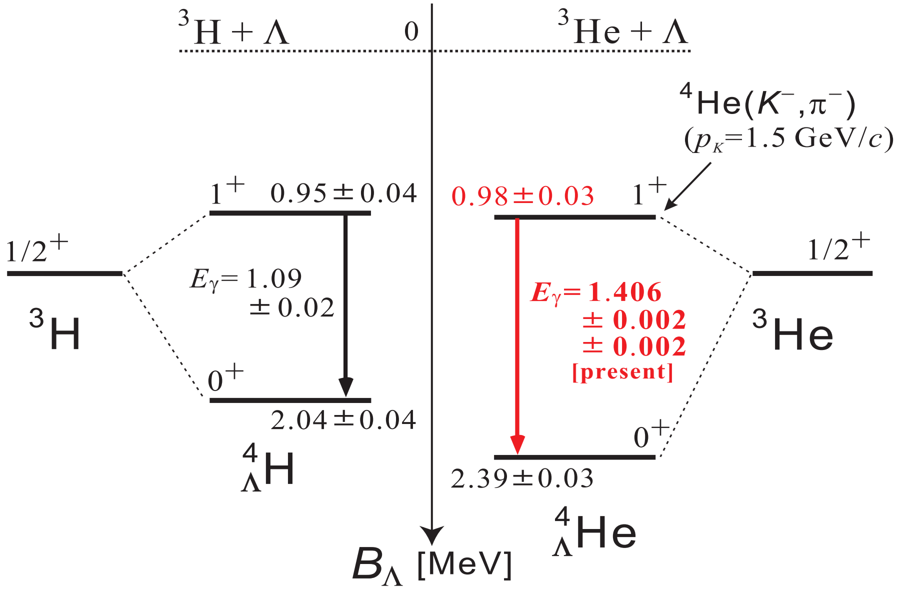
Recent $A = 3, 4$ few-body calculations

- **A. Nogga, NPA 914 (2013) 140**
  Faddeev & Faddeev-Yakubovsky (chiral LO & NLO).
- **E. Hiyama et al., PRC 89 (2014) 061302(R)**
  Jacobi-coordinates Gaussian basis (Nijmegen soft-core).
- **R. Wirth et al., PRL 113 (2014) 192502.**
  ab-initio Jacobi-NCSM (chiral LO).

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

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



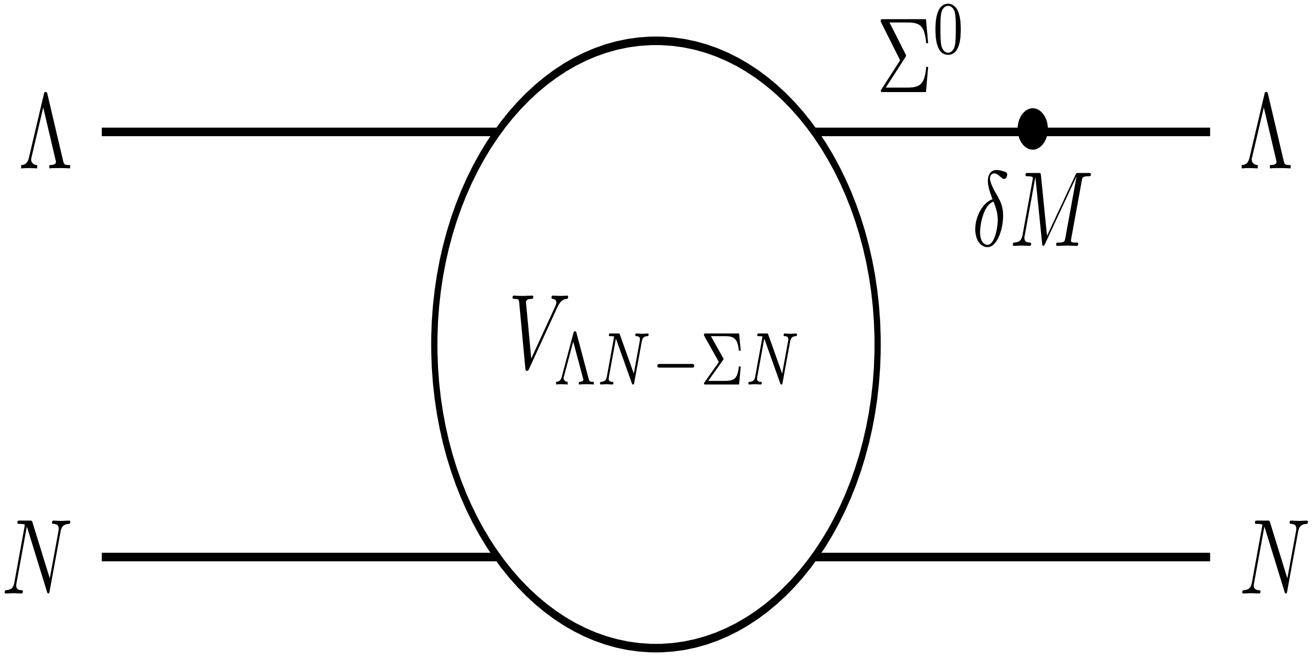


MAMI's new value $B_\Lambda(^{4}_{\Lambda}\mathrm{H})=2.12\pm0.01\pm0.09$ MeV, consistent with emulsion value, obtained by measuring decay π^- in $^{4}_{\Lambda}\mathrm{H}\rightarrow{}^{4}\mathrm{He}+\pi^-$ [PRL 114 (2015) 232501].

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

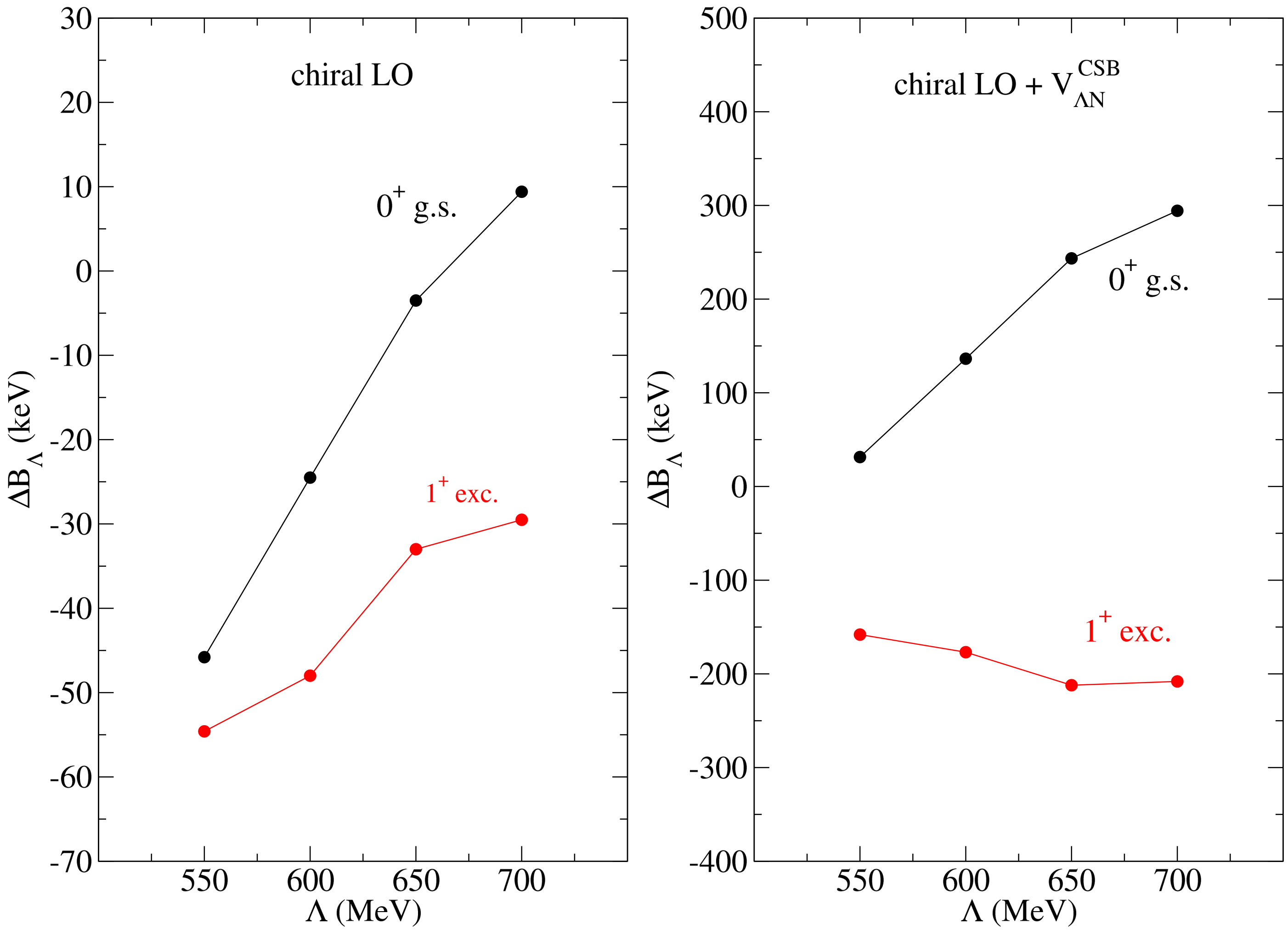
350±60 keV in $^{4}_{\Lambda}$H-$^{4}_{\Lambda}$He vs. ≈-70 keV in ^{3}H-^{3}He.

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.

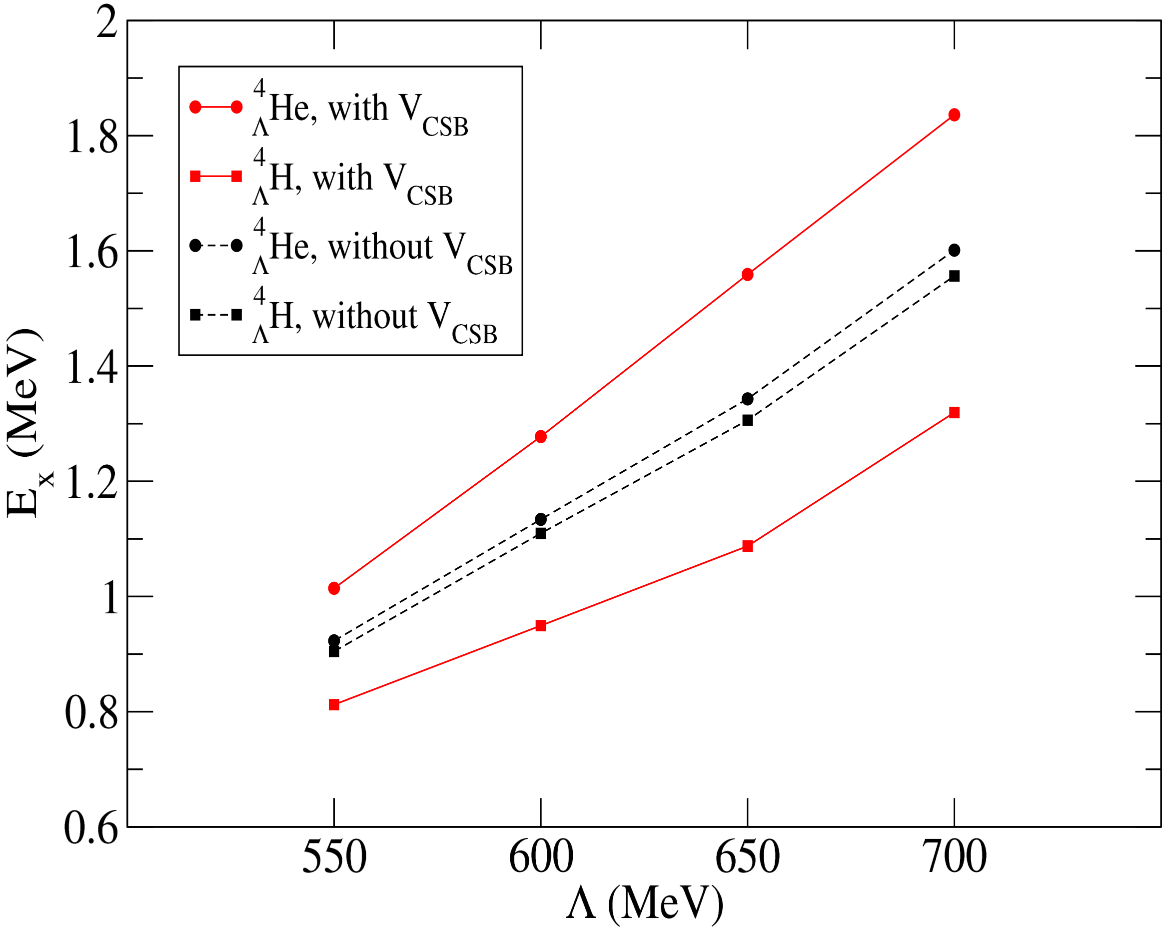


A=4 CSB: **D. Gazda, A. Gal, arXiv:1512.01049**

$B_\Lambda(0^+) \approx$ 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.



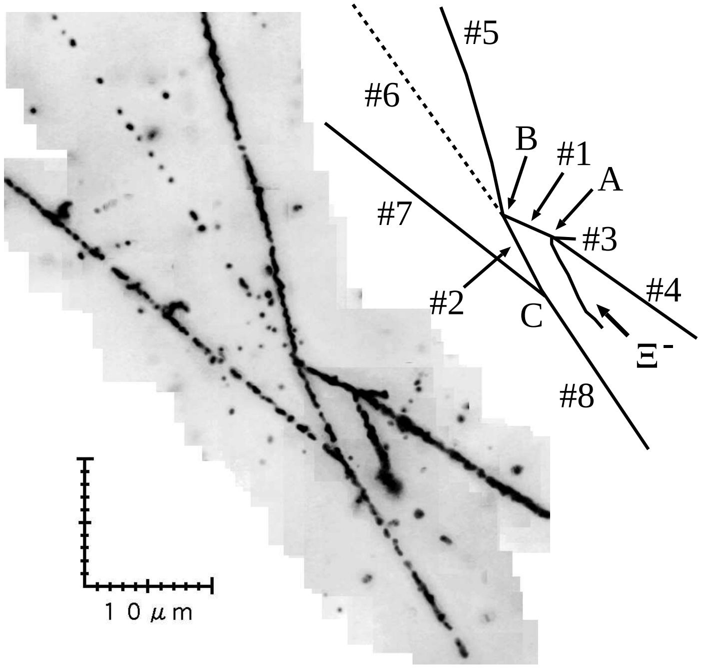
D. Gazda, A. Gal, arXiv:1512.01049

EFT LO cutoff momentum (Λ) dependence of $E_x(0^+ \rightarrow 1^+)$ at HO $\hbar\omega$=30,32 MeV. [exp: $E_x(^{4}_{\Lambda}\text{He})=1.41\pm0.02$ MeV]

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

Λ=600 MeV: $\Delta E_x=0.33\pm0.03$ MeV [exp: 0.32 ± 0.02 MeV]

$\Lambda\Lambda$ hypernuclei



Nagara event, ${}_{\Lambda\Lambda}^{\;6}\mathrm{He}$, H. Takahashi et al. (KEK-E373) PRL 87 (2001) 212502

$B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{\;6}\mathrm{He}_{\mathrm{g.s.}}) = 6.91 \pm 0.16$ **MeV, unambiguously determined.**

- A: Ξ^- capture $\Xi^- + {}^{12}\mathrm{C} \;\rightarrow\; {}_{\Lambda\Lambda}^{\;6}\mathrm{He} + t + \alpha$
- B: weak decay ${}_{\Lambda\Lambda}^{\;6}\mathrm{He} \;\rightarrow\; {}_{\Lambda}^{5}\mathrm{He} + p + \pi^-$ (no ${}_{\Lambda\Lambda}^{\;6}\mathrm{He} \;\rightarrow\; {}^{4}\mathrm{He} + H$)
- C: nonmesonic weak decay of ${}_{\Lambda}^{5}\mathrm{He}$ to two $Z = 1$ recoils & neutron

Binding energy consistency of $\Lambda\Lambda$ hypernuclei

event	${}^{A}_{\Lambda\Lambda}\mathrm{Z}$	$B^{\mathrm{exp}}_{\Lambda\Lambda}$	$B^{\mathrm{CM}}_{\Lambda\Lambda}$ †	$B^{\mathrm{SM}}_{\Lambda\Lambda}$ ††
E373-Nagara	${}^{6}_{\Lambda\Lambda}\mathrm{He}$	6.91 ± 0.16	6.91 ± 0.16	6.91 ± 0.16
E373-DemYan	${}^{10}_{\Lambda\Lambda}\mathrm{Be}$	14.94 ± 0.13 ‡	14.74 ± 0.16	14.97 ± 0.22
E373-Hida	${}^{11}_{\Lambda\Lambda}\mathrm{Be}$	20.83 ± 1.27	18.23 ± 0.16	18.40 ± 0.28
E373-Hida	${}^{12}_{\Lambda\Lambda}\mathrm{Be}$	22.48 ± 1.21	–	20.72 ± 0.20
E176	${}^{13}_{\Lambda\Lambda}\mathrm{B}$	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 ${}^{10}_{\Lambda\Lambda}\mathrm{Be}$ 1st excited state $2^+(3.04\ \mathrm{MeV})$

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

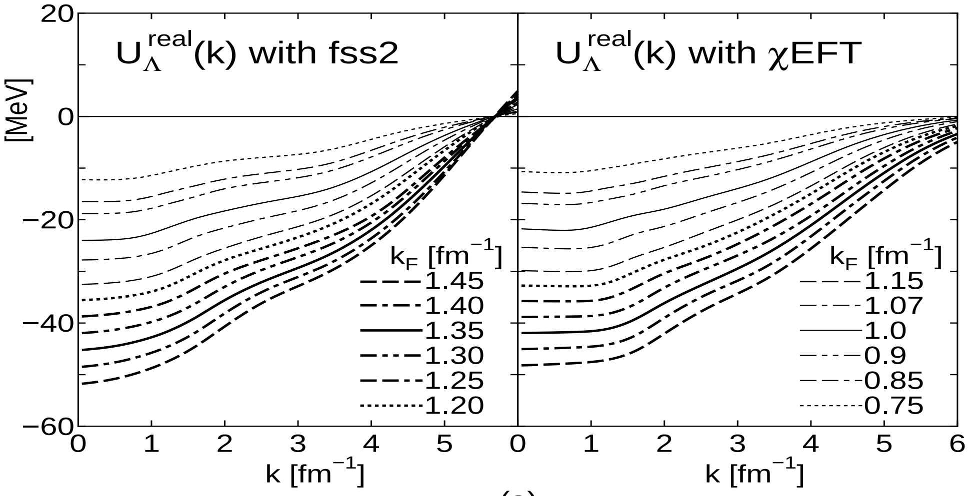
- Hida-event [PTPS **185** (2010) 335] offers no clue
- $B^{\mathrm{SM}}_{\Lambda\Lambda} \approx B^{\mathrm{CM}}_{\Lambda\Lambda}$, but SM spans a wider A range

$\Lambda\Lambda$ conclusions

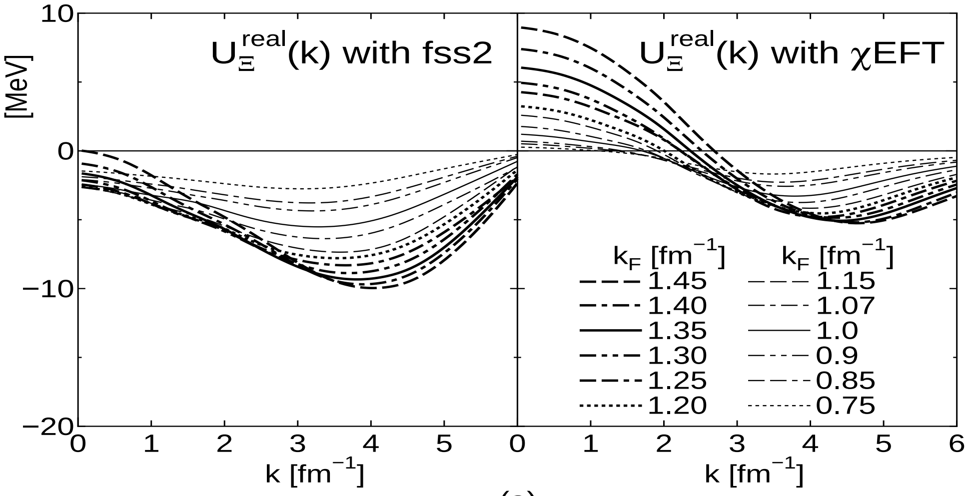
- Relatively weak $\Lambda\Lambda$ interaction
  $< V_{\Lambda\Lambda} > \approx 0.6$ MeV, $|a_{\Lambda\Lambda}| < 1$ fm
- Onset of $\Lambda\Lambda$ binding likely with ${}^{5}_{\Lambda\Lambda}\mathrm{H}$ & ${}^{5}_{\Lambda\Lambda}\mathrm{He}$
- Shell model works well beyond ${}^{6}_{\Lambda\Lambda}\mathrm{He}$
- 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 $\bar{p}p \to \Xi^-\bar{\Xi}^+$

Hyperons in nuclear matter

and $S = -3, -4$ systems



(a)



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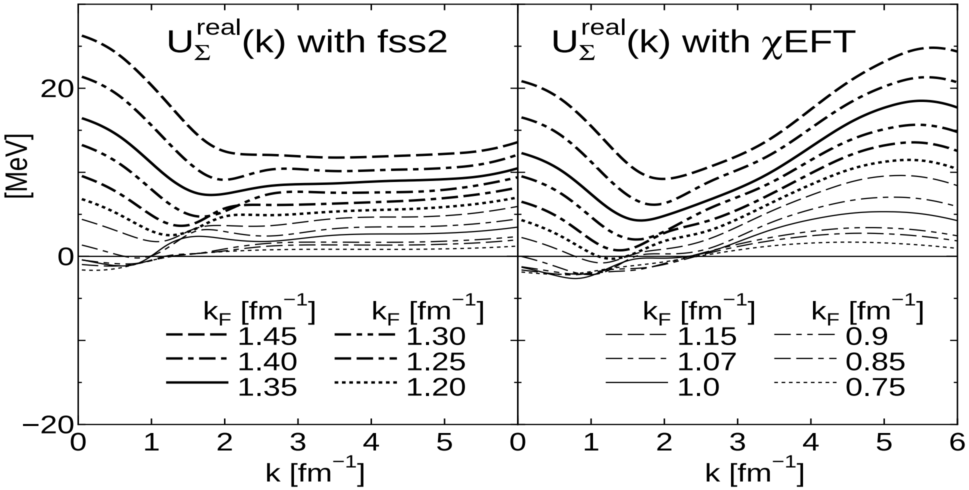

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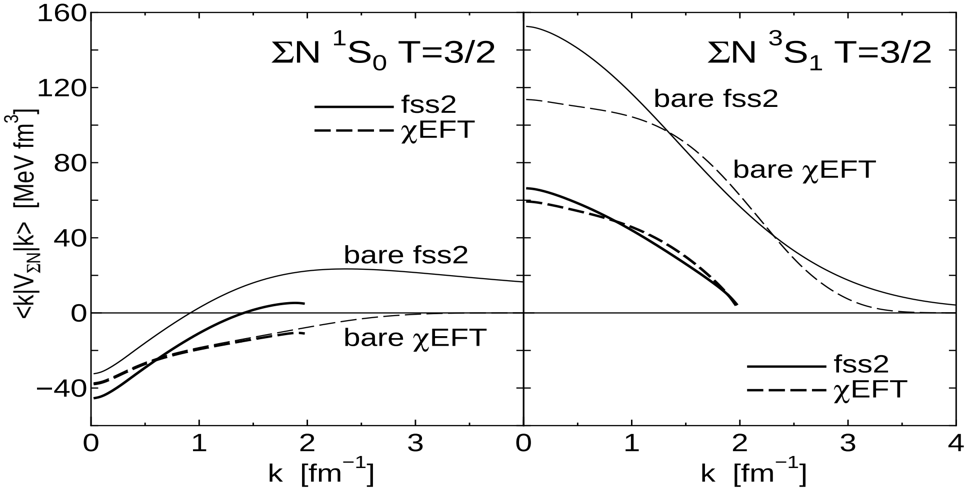


(b)

Kohno, PRC **81** (2010) 014003 Nuclear matter hyperon s.p. potentials

QM fss2 Fujiwara et al. (2007) χ EFT (LO) Polinder et al. (2007)

χ EFT (NLO) Haidenbauer- Meißner (2015).

$\mathcal{S} = -2, -3, -4$ deuteron-like $L = 0$ dibaryon candidates

	$\Sigma\Sigma$ $(I = 2, {}^1S_0)$	$\Lambda\Xi$ $(I = \frac{1}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I = \frac{3}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I = \frac{3}{2}, {}^3S_1)$	$\Xi\Xi$ $(I = 1, {}^1S_0)$
NSC97	+	−	+	+	+
EFT (LO)	−	+	+	−	+
EFT (NLO)	−	−	−	−	−

NSC97: V.G.J. Stoks, T.A. Rijken, Phys. Rev. C **59** (1999) 3009

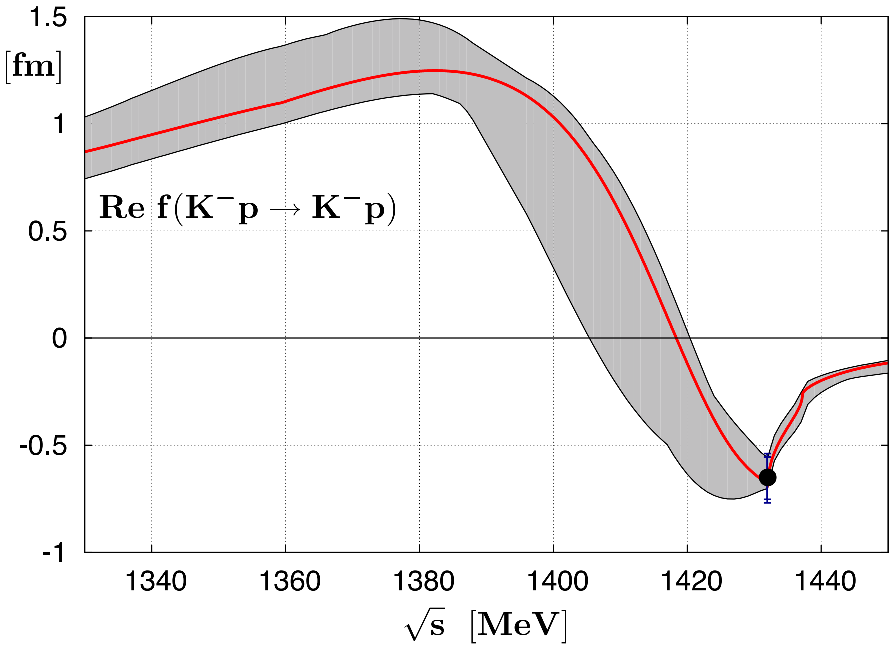
EFT (LO): J. Haidenbauer, U.-G. Meißner, Phys. Lett. B **684** (2010) 275

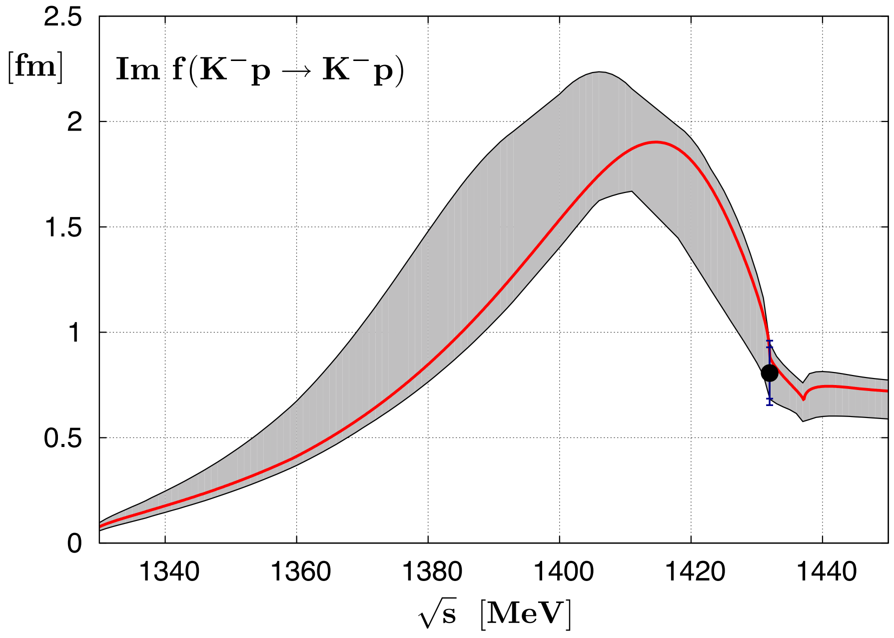
EFT (NLO): JH, UGM, S. Petschauer, Eur. Phys. J. A **51** (2015) 17

- Systematics of EFT (LO): The $\mathcal{S} = -3, -4$ sectors require only the 5 LECs determined in the YN sector fit, independently of the 6th LEC required in the $\mathcal{S} = -2$ sector (this LEC is consistent with zero). Hence get PREDICTIONS.
- ${}^1S_0$ in SU(3)$_\mathrm{f}$ **27** (as nn), ${}^3S_1$ in SU(3)$_\mathrm{f}$ $\overline{\mathbf{10}}$ (as deuteron).
- Model dependence is assessed by varying a cutoff momentum in the range 550 – 700 MeV/c. **SU(3) breaking aborts binding at NLO.**
- **HALQCD Collab. predicts $N\Omega$ 2^+ bound state [NPA 928 (2014) 89].**

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)→ 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.)

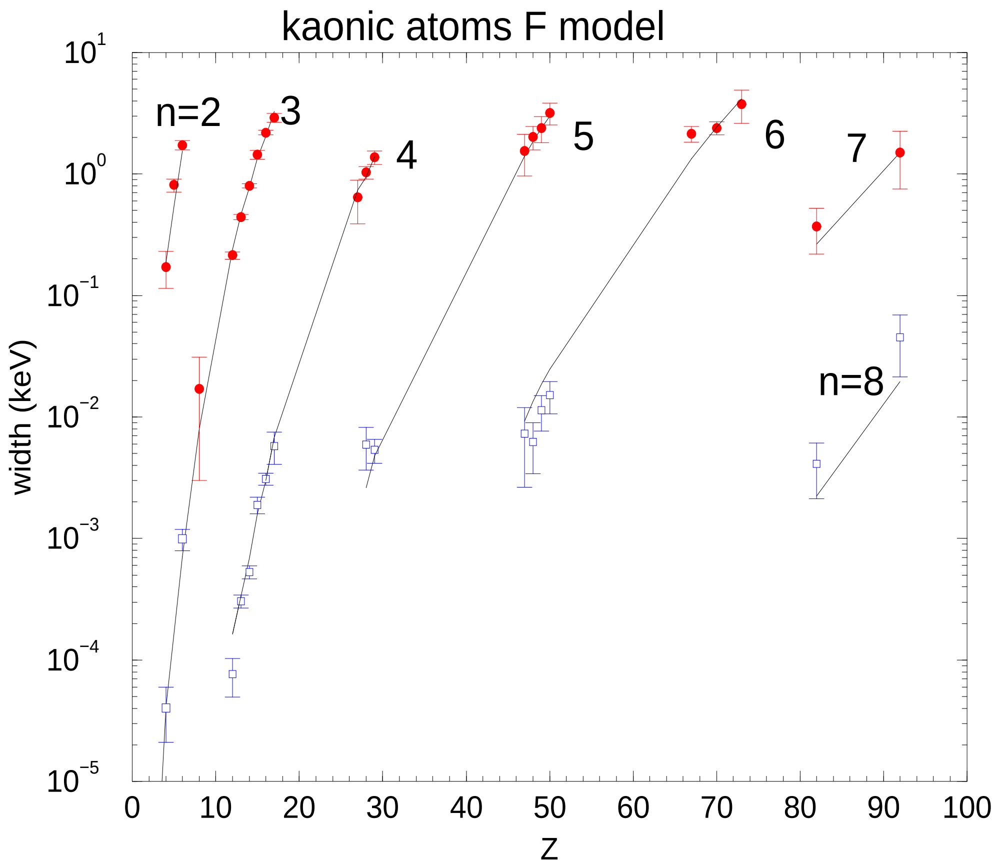
(MeV)	chiral, energy dep. calculations				non-chiral, static calculations			
	var. [1]	var. [2]	Fad. [3]	Fad. [4]	var. [5]	Fad. [6]	Fad. [7]	var. [8]
B	16	17–23	9–16	32	48	50–70	60–95	40–80
Γ	41	40–70	34–46	49	61	90–110	45–80	40–85

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)**

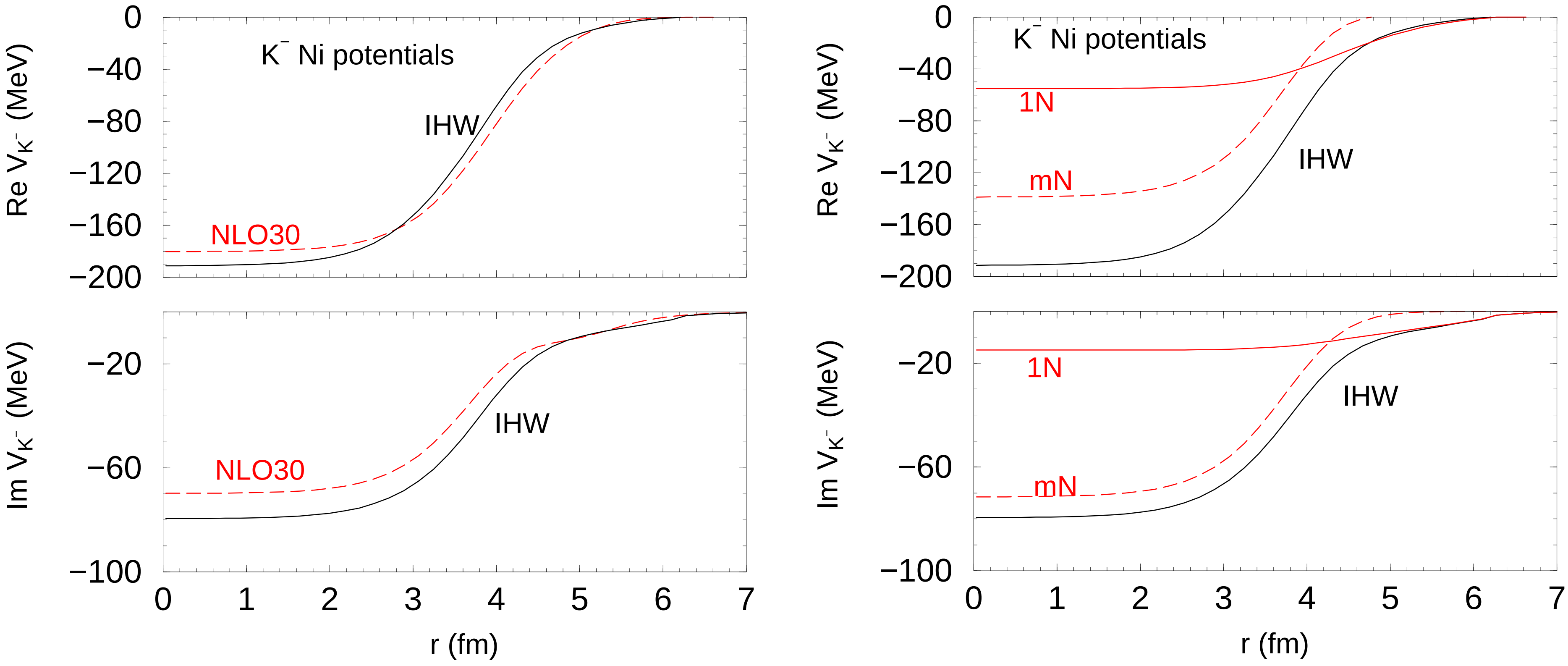
What do K^- atoms tell us?



K^-_{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.

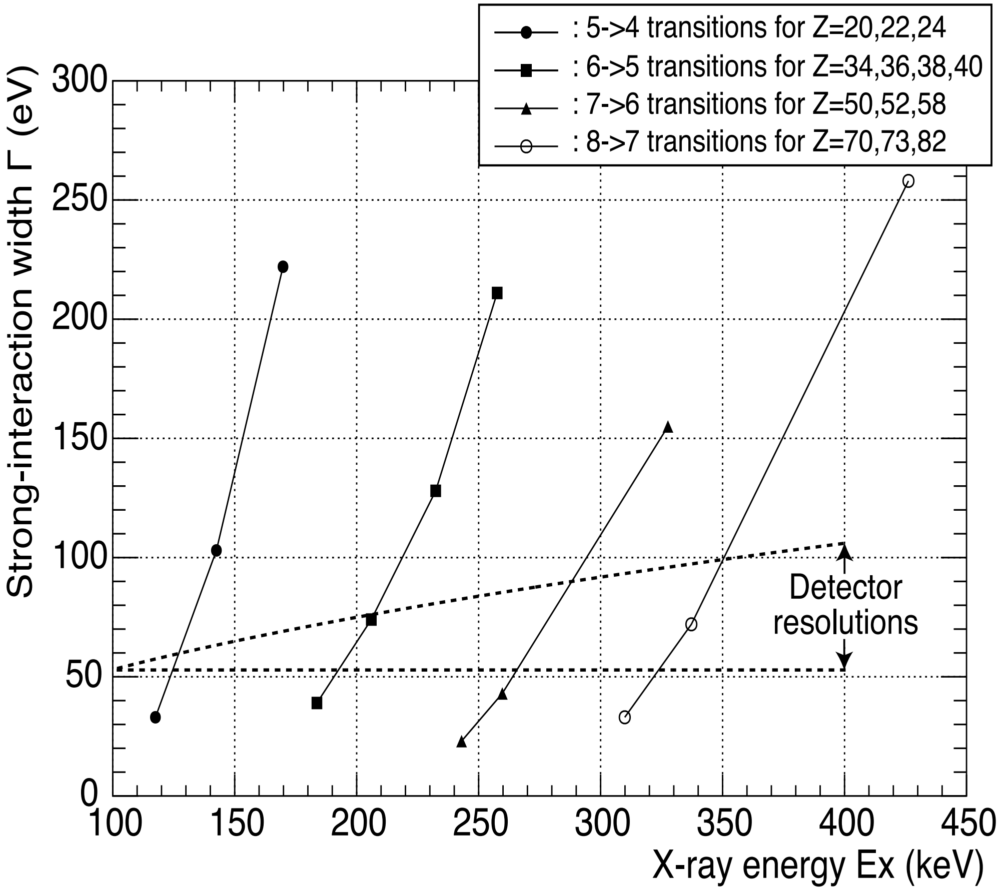
Kaonic-atom best-fit V_{K^-} for Ni & its breakdown into in-medium 1N and empirical m(any)N contributions.

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

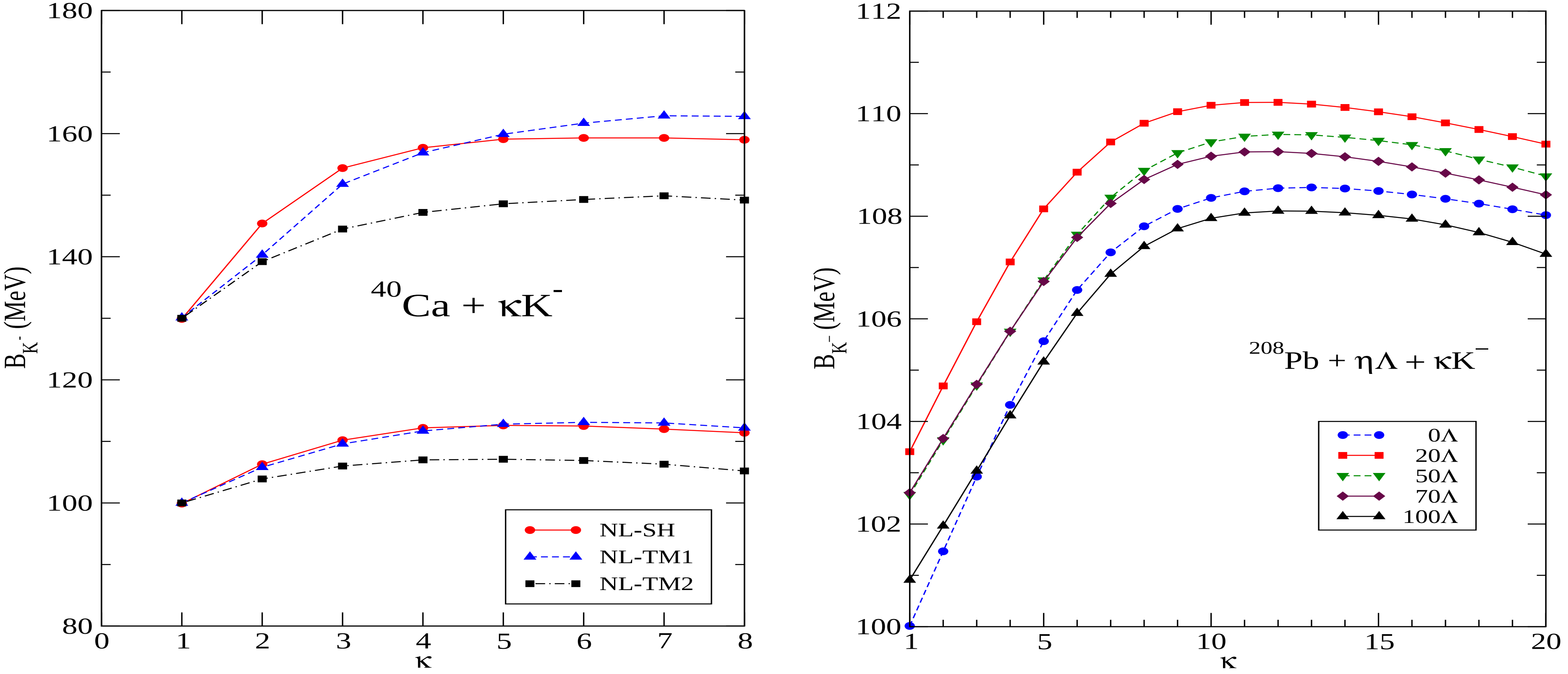
Upper level sensitive to 1N & lower level to mN terms.

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

Targets for K^- atom measurements



For these targets, both upper-level and lower-level can be studied simultaneously owing to a ≈50 eV resolution of new microcalorimeter detectors.



Gazda-Friedman-Gal-Mareš: PRC **77** (2008) 045206, **80** (2009) 035205

Saturation of $B_{\bar{K}}(\kappa)$ in RMF for multi-K^- nuclei & hypernuclei.

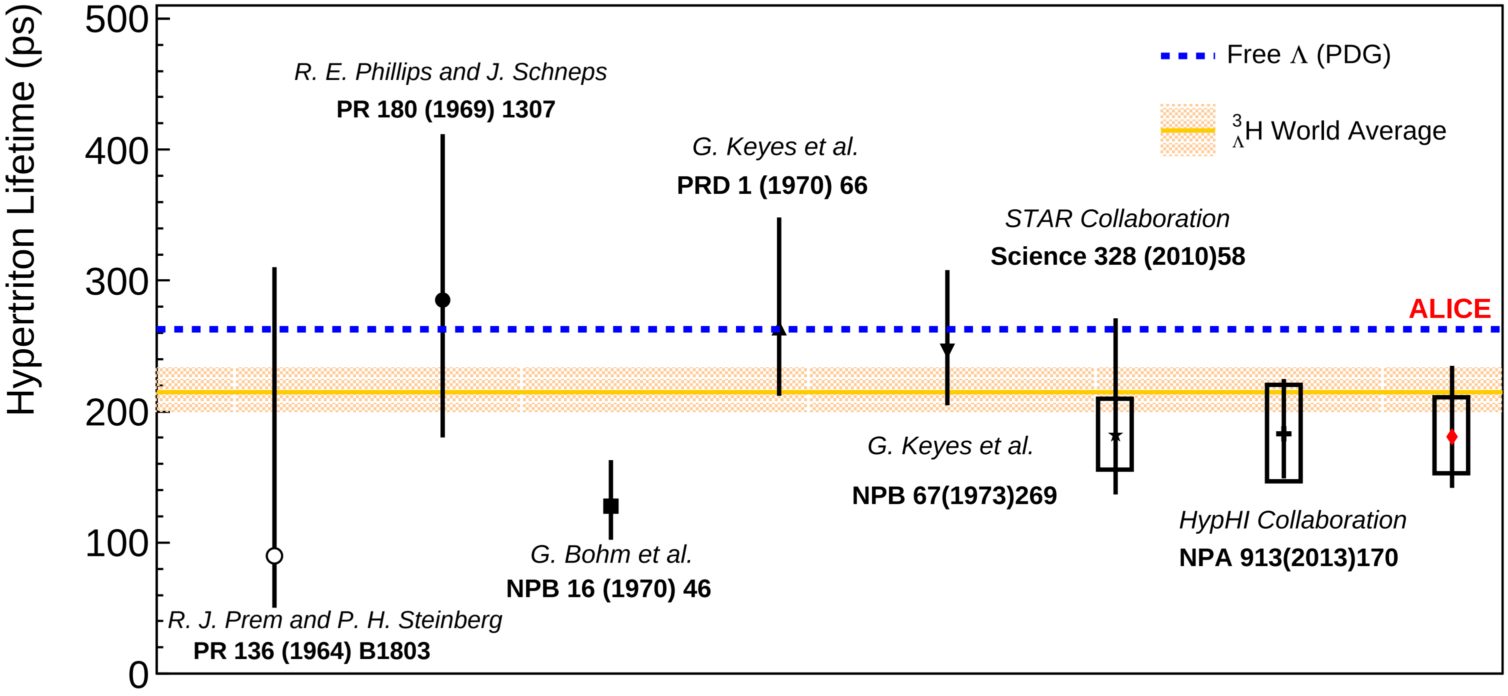
Vector-meson repulsion among $\bar{K}$ mesons. **$\bar{K}$ mesons do not replace hyperons in self-bound strange matter.**

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 [Λ^*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 Θ^+ pentaquark traces in nuclei by**
  doing (p,K$^+$).
- **Resolve the ${}^3_\Lambda$H lifetime puzzle (see next page).**

Recent HIC ${}^{3}_{\Lambda}$H lifetime measurements



ALICE Collaboration, PLB 754 (2016) 360.

$\tau({}^{3}_{\Lambda}\mathrm{H})$ from heavy-ion reactions much shorter than τ_{Λ}.

$\tau({}^{3}_{\Lambda}\mathrm{H}) \approx \tau_{\Lambda}$ in microscopic calculations (Kamada et al. 1998).

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

- **E03: X rays from Ξ^- atoms**
- **E05:** $^{12}\mathrm{C}(K^-,K^+)^{12}_{\Xi}\mathrm{Be}$
- **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**