Hypernuclear Spectroscopy

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Florida International University

Hall A Collaboration Meeting

December 8-9, 2014

Thomas Jefferson National Accelerator Facility

Newport News, VA

JLab Hypernuclear Experiments

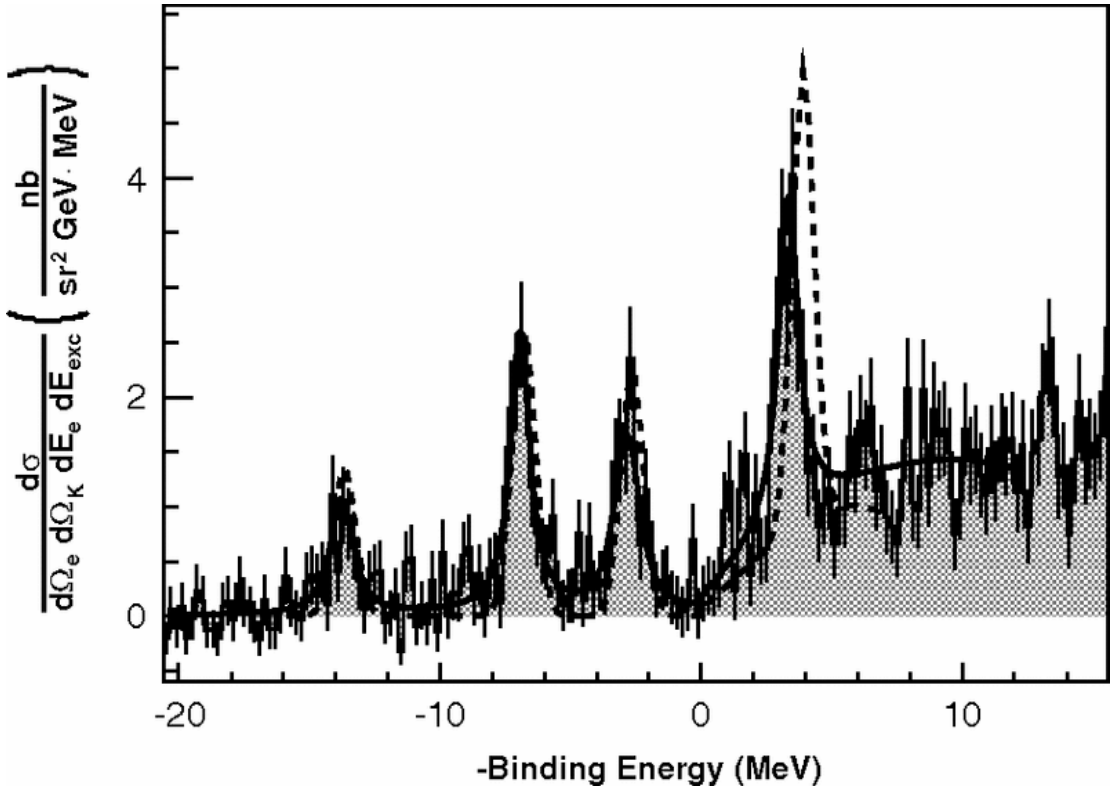
- E-91-016 A C Electroproduction of Kaons and Light Hypernuclei
- E-89-009 A C Investigation of the Spin Dependence of the LN Effective Interaction in the P Shell
- E-01-011 A C Spectroscopic Study of Lambda Hypernuclei Up To Medium-Heacy Mass Region Through the (e,e'k+) Reaction
- E-05-115 A C Spectroscopic investigation of the hypernuclei in the wide mass region using (e,e'k+) reaction
- E-02-017 A C Status of the LS=1 Hadronic Weak Interaction Program (update to 99-003)
- C-08-012 C C Study of Light Hypernuclei by Pionic Decay at Jlab
- E-94-107 A A High Resolution Hypernuclear 1p shell Spectroscopy
- E-07-012 A A The Angular Dependence of 16O(e,e'K)16N_lambda and H(e,e'K)lambda
- **PR12-13-002 D A A Study with High Precision on the Electro-production of the Lambda and Lambda-Hypernuclei in the Full Mass Range**

Jlab Hypernuclear Papers

1. **Spectroscopy of $^{9}_{\Lambda}$Li by electroproduction**
   Hall A Collaboration (G.M. Urciuoli et al.), arXiv:1405.5839 [nucl-ex]. (submitted)
2. **The experiments with the High Resolution Kaon Spectrometer at JLab Hall C and the new spectroscopy of $^{12}_{\Lambda}$B hypernuclei**
   HKS Collaboration (L. Tang et al.), Phys.Rev. C90 (2014) 034320.
3. **Observation of the Helium 7 Lambda hypernucleus by the (e,e'K+) reaction**
   HKS Collaboration (S.N. Nakamura et al.), Phys.Rev.Lett. 110 (2013) 012502.
4. **High Resolution Spectroscopy of $^{16}_{\Lambda}$N by Electroproduction**
   Hall A Collaboration (F. Cusanno et al.), Phys.Rev.Lett. 103 (2009) 202501.
5. **High Resolution Spectroscopy of $^{12}_{\Lambda}$B by Electroproduction**
   Hall A Collaboration (M. Iodice et al.), Phys.Rev.Lett. 99 (2007) 052501.
6. **Hypernuclear spectroscopy using the (e,e'K^+) reaction**
   HNSS Collaboration (L. Yuan et al.), Phys.Rev. C73 (2006) 044607.
7. **High resolution spectroscopy of the $^{12}_{\Lambda}$B hypernucleus produced by the (e,e'K^+) reaction**
   HNSS Collaboration (T. Miyoshi et al.), Phys.Rev.Lett. 90 (2003) 232502.
8. **Angular distributions for $^{3,4}_{\Lambda}$H bound states in the ^{3,4}He-4(e,e'K^+) reaction**
   E91-016 Collaboration (F. Dohrmann et al.), Phys.Rev.Lett. 93 (2004) 242501.

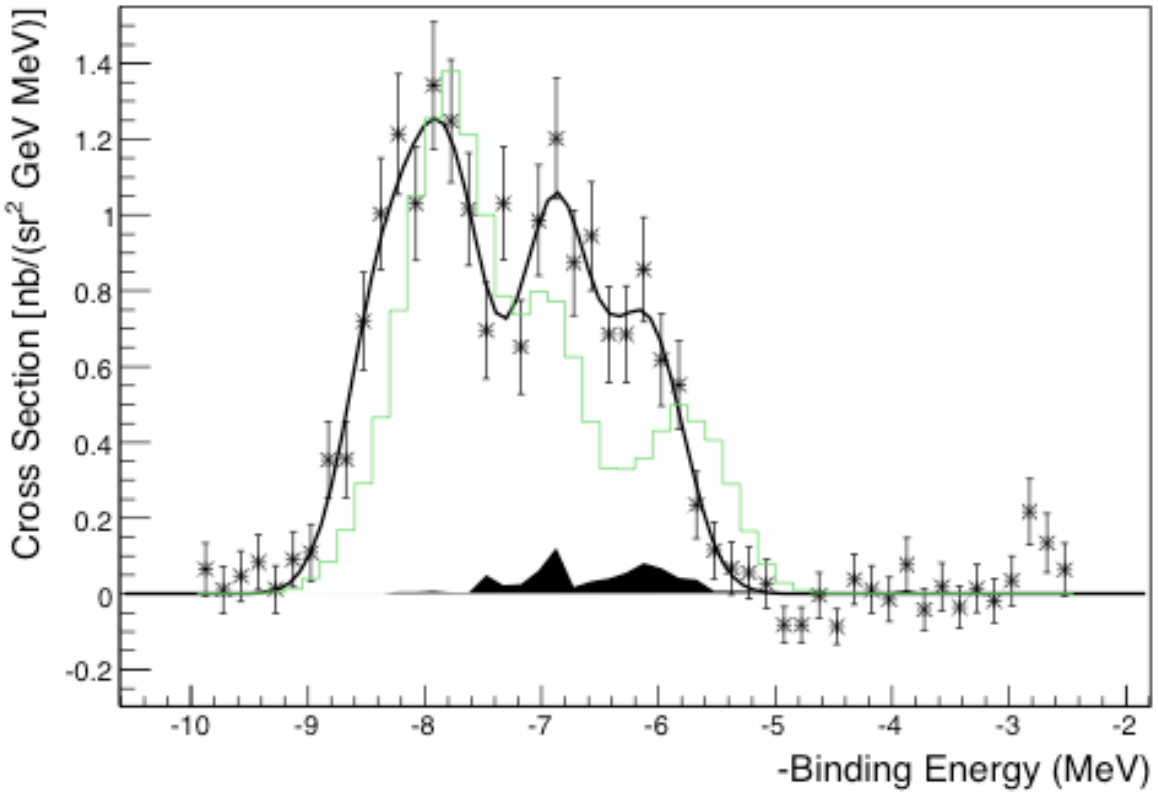
High Resolution Spectroscopy of $^{16}_{\Lambda}$N by Electroproduction

Hall A Collaboration (F. Cusanno et al.), Phys.Rev.Lett. 103 (2009) 202501



Spectroscopy of $^{9}_{\Lambda}$Li by electroproduction

Hall A Collaboration (G.M. Urciuoli et al.), arXiv:1405.5839 [nucl-ex]. (submitted)



$^{12}C(e,e'K^+)^{12}_{\Lambda}B$

0.5 MeV (FWHM)

Absolute MM calibration

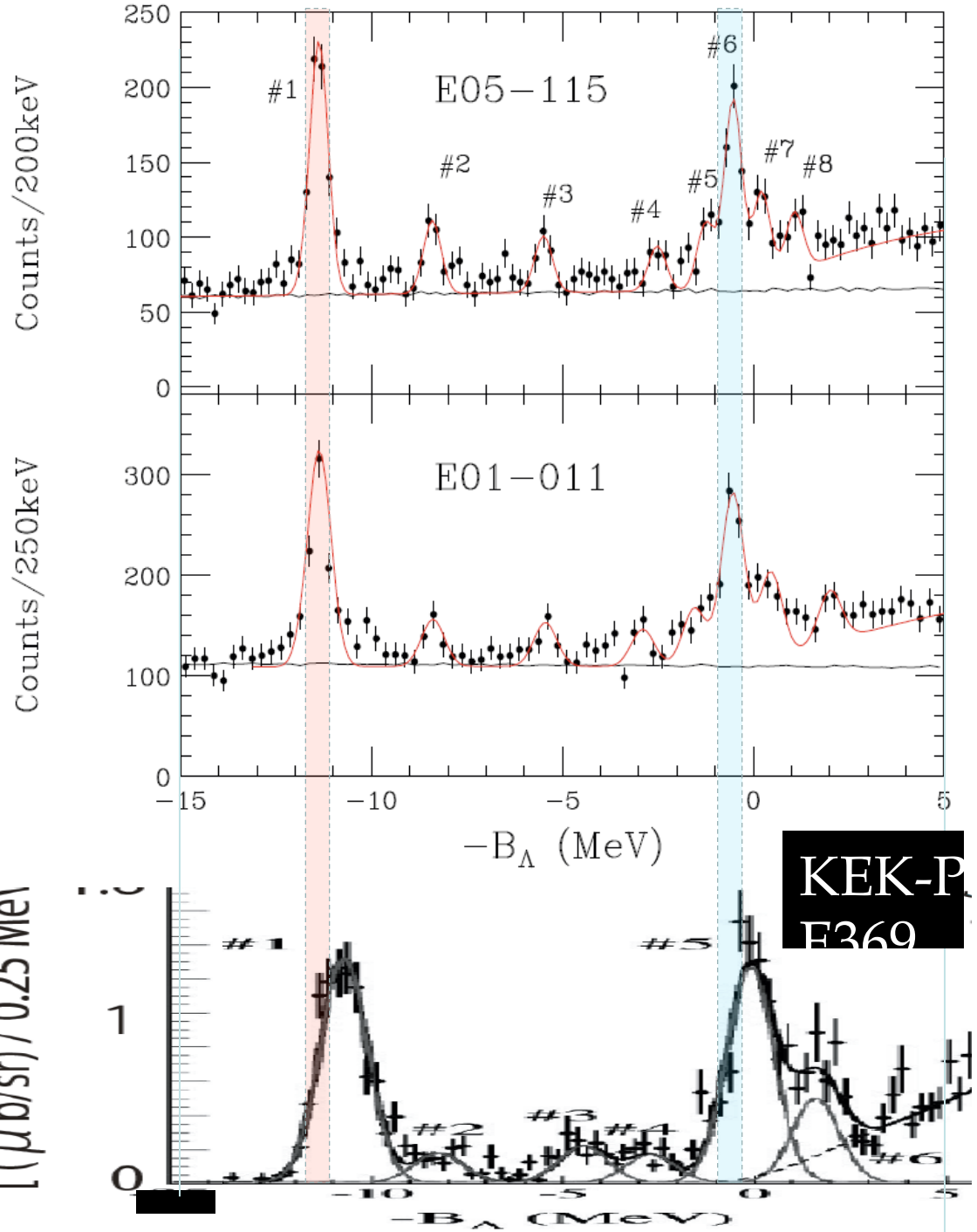
0.7 MeV (FWHM)

L.Tang, C.Chen, T.Gogami *et al.*
Phys. Rev. C **90** (2014) 034320.

$^{12}C(\pi^+,K^+)^{12}_{\Lambda}C$

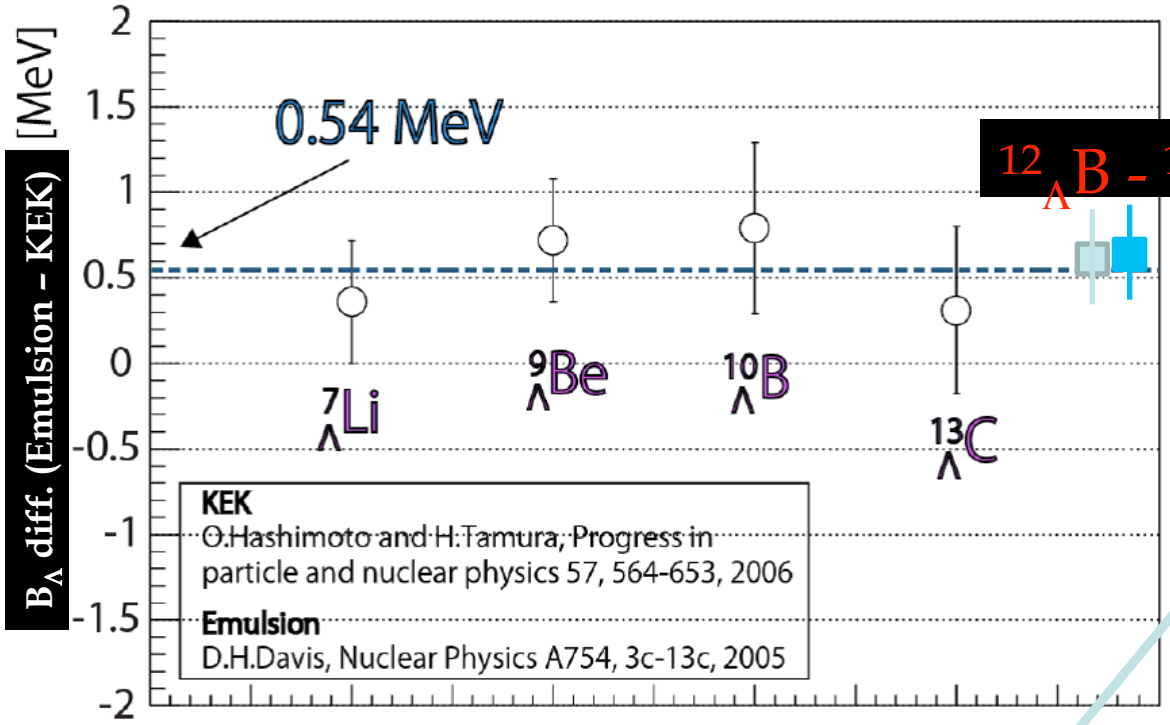
1.45 MeV (FWHM)

$^{12}_{\Lambda}C_{gs}$ energy from emulsion



Possible shift of $^{12}_{\Lambda}C_{gs}$ B_{Λ}

$^{12}_{\Lambda}B$ - $^{12}_{\Lambda}C$: 0.57 ± 0.19 MeV (emulsion)
0.62 ± 0.19 MeV (E05-115 – emulsion)



Large CSB
or
CSB ~ 0 with

T. Gogami, Doctor thesis, (2014) Tohoku U.

$^{12}_{\Lambda}C$ is very special or B_{Λ} ($^{12}_{\Lambda}C_{gs}$) is shifted by ~0.5 MeV.

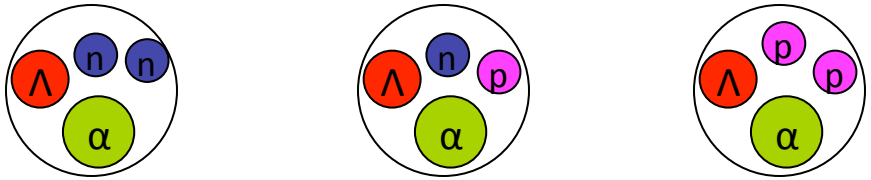
Charge Symmetry Breaking

A=4 Isospin Doublet:

$^{4}_{\Lambda}$He $B_{ground}(0^+) = 2.39 \pm 0.03$ MeV $B_{excited}(1^+) = 1.24 \pm 0.06$ MeV

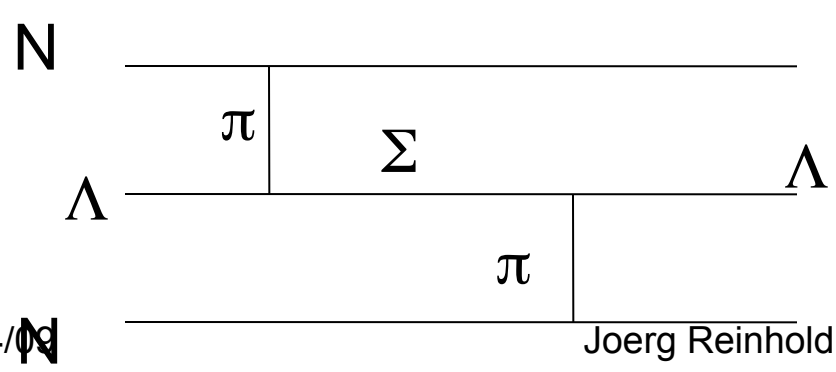
$^{4}_{\Lambda}$H $B_{ground}(0^+) = 2.04 \pm 0.04$ MeV $B_{excited}(1^+) = 1.00 \pm 0.06$ MeV

A=7 Isospin Triplet



$^{7}_{\Lambda}$He $^{7}_{\Lambda}$Li* $^{7}_{\Lambda}$Be

Source Λ - Σ mixing and the mass differences in the Σ-multiplet



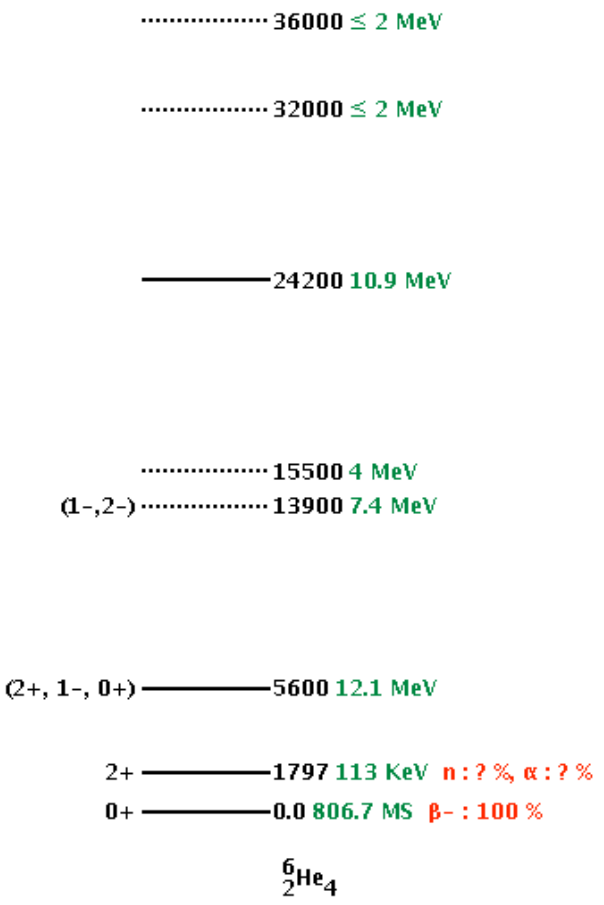
$$m_{\Sigma^+} = 1189.37 \text{ MeV}$$

$$m_{\Sigma^0} = 1192.64 \text{ MeV}$$

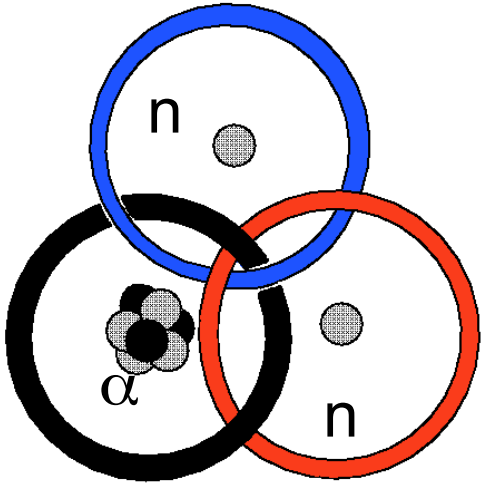
$$m_{\Sigma^-} = 1197.45 \text{ MeV}$$

^{6}He Level Scheme

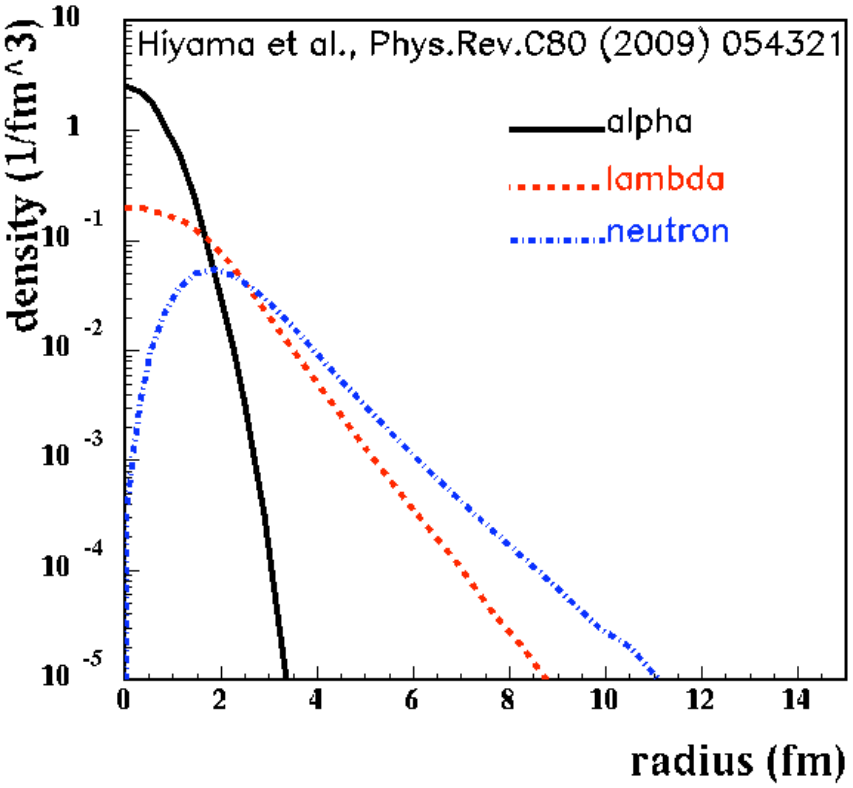
National Nuclear Data Center
(http://www.nndc.bnl.gov/chart)/

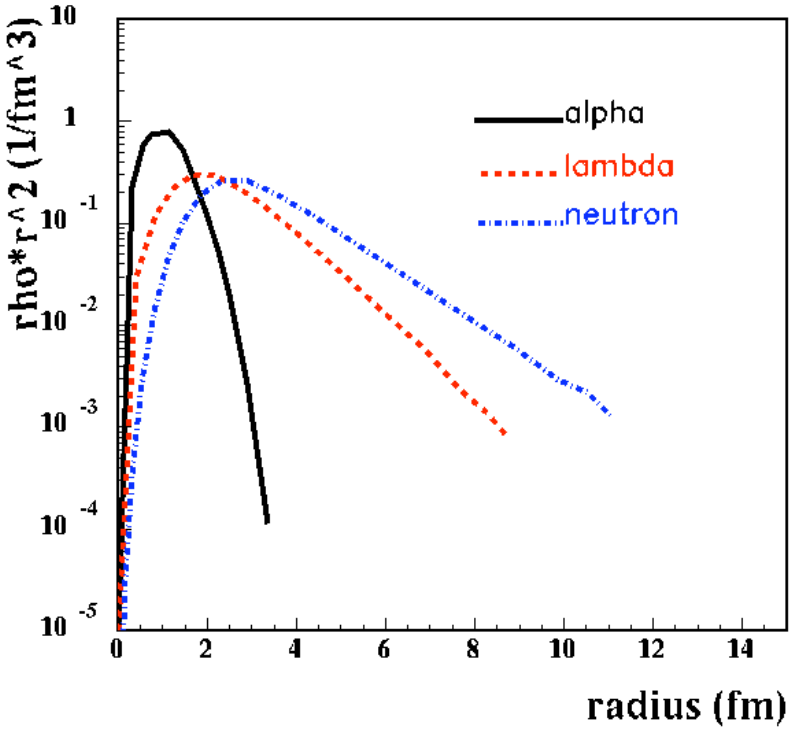


- 2n halo
- all excited states unbound
- Borromean nucleus

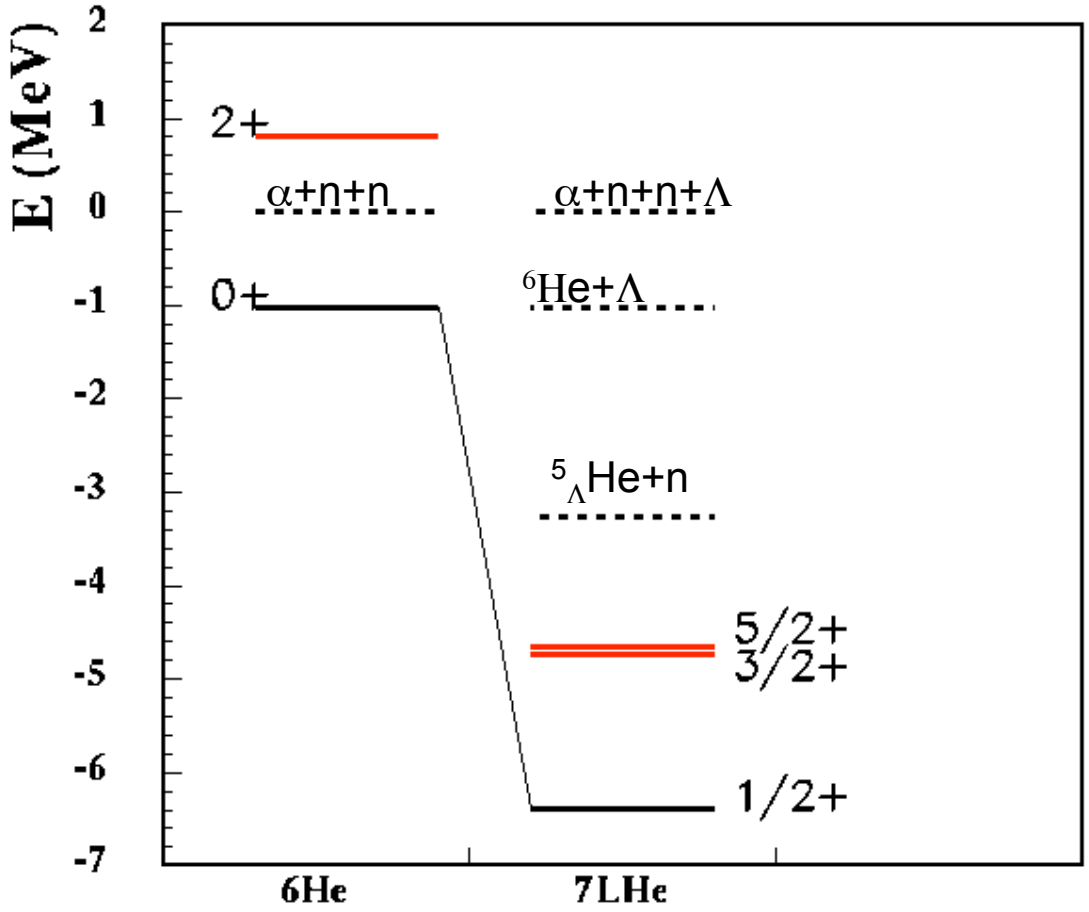


$^{7}_{\Lambda}$He Density Distributions



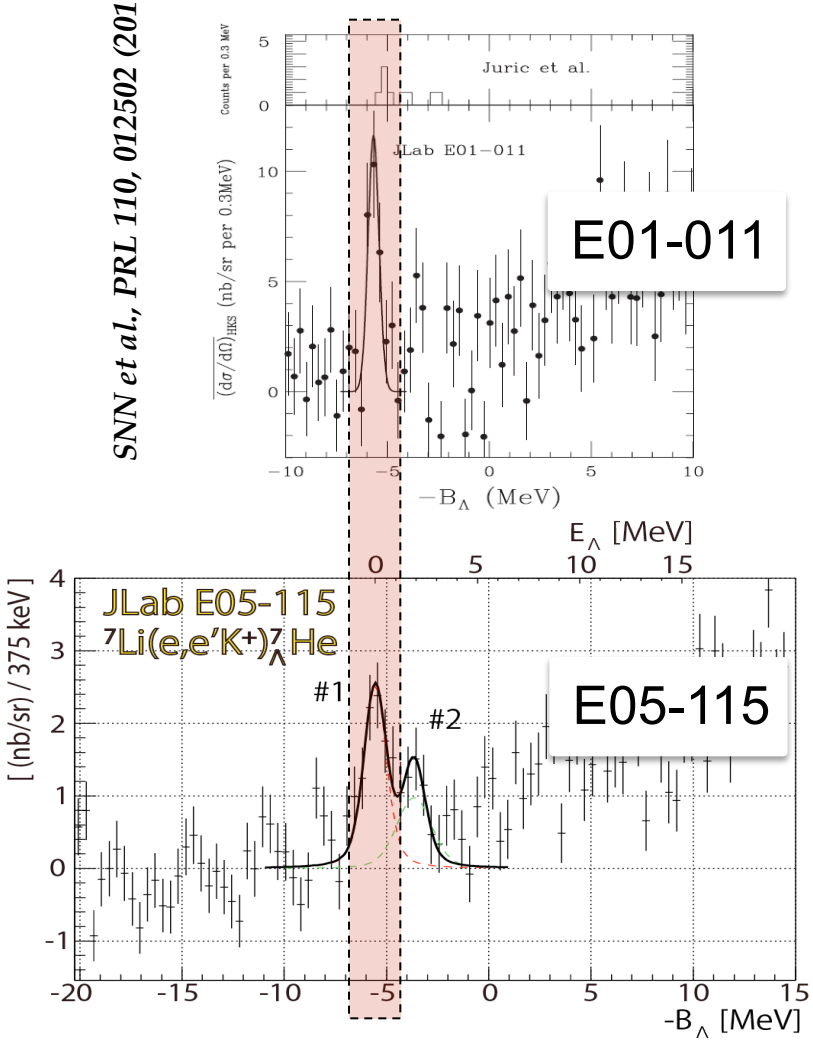


Calculated Energy Levels



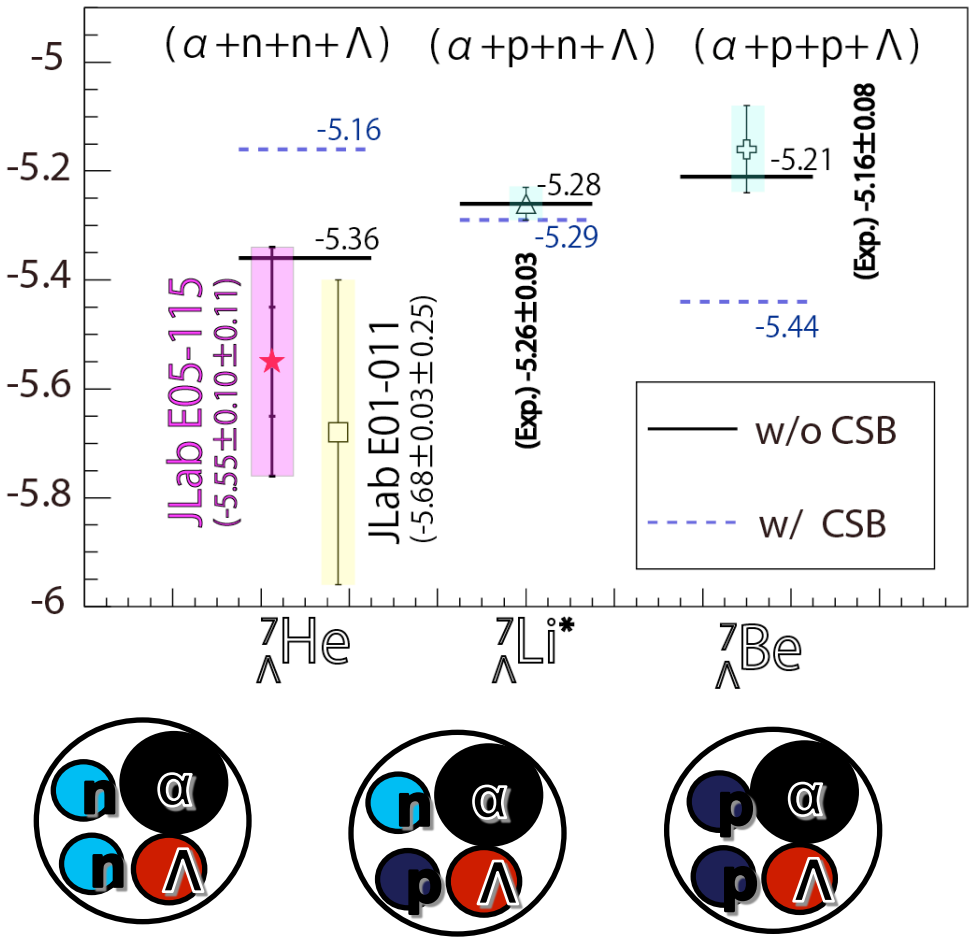
CSB interaction test in A=7 iso-triplet comparison

SNN et al., PRL 110, 012502 (2013)

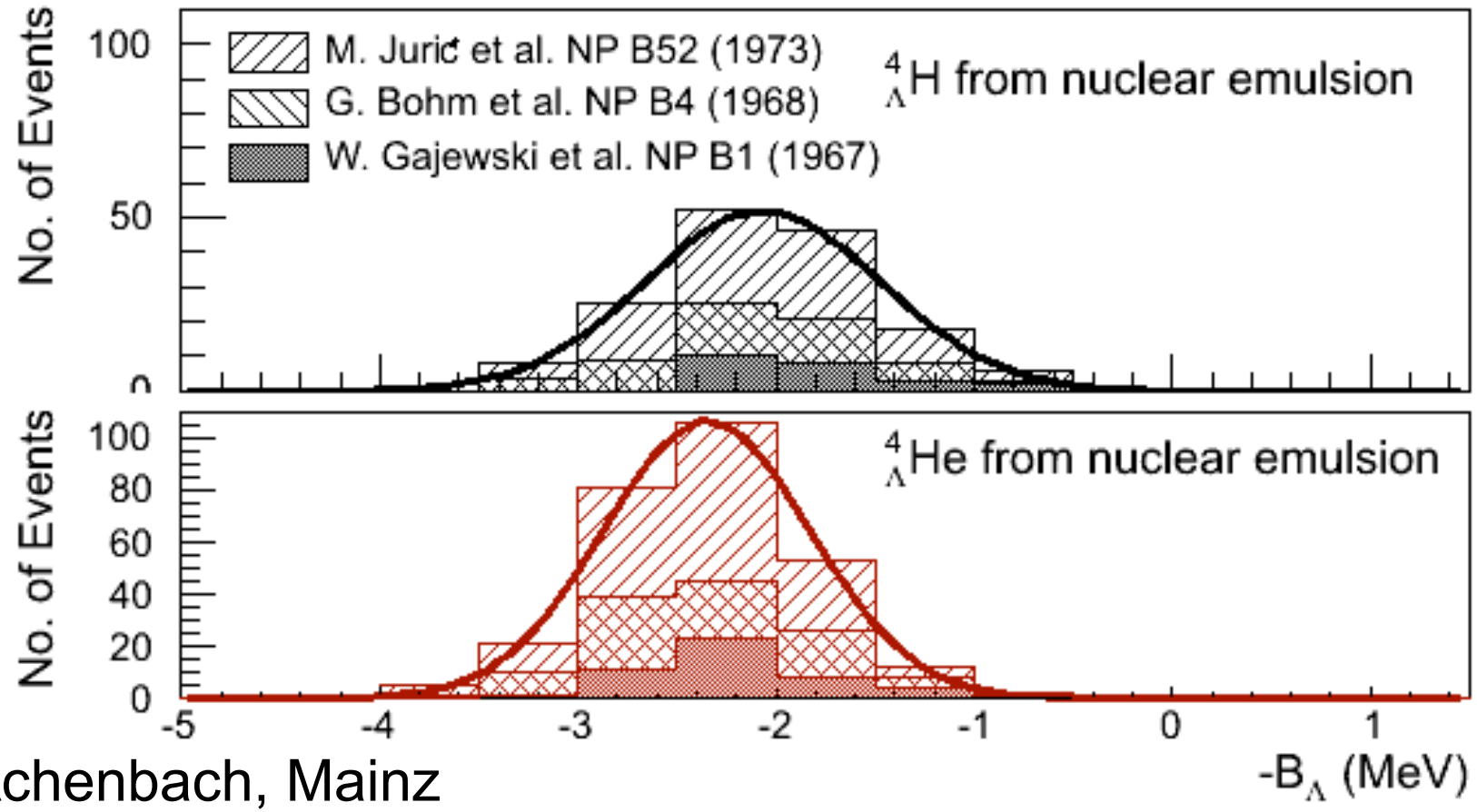


T.Gogami, Doctor Thesis (2014) Tohoku Univ.

Prediction by E.Hiyama et al.
PRC80, 054321 (2009)



World data on *A* = *4* system

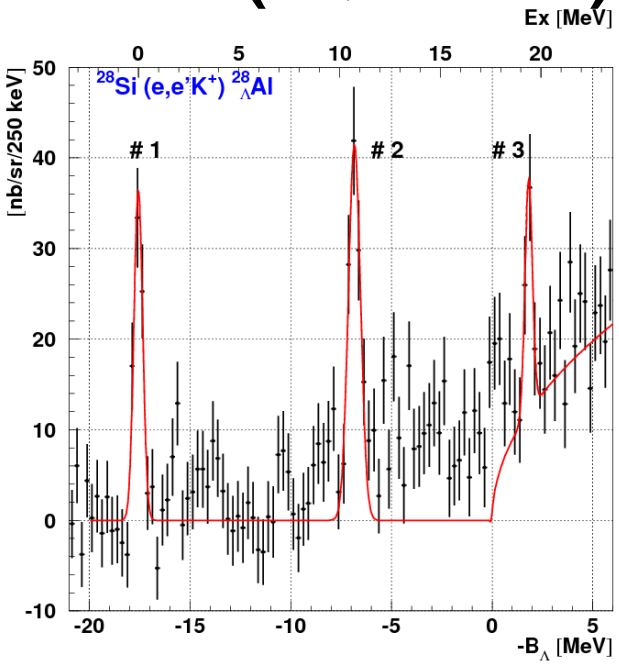


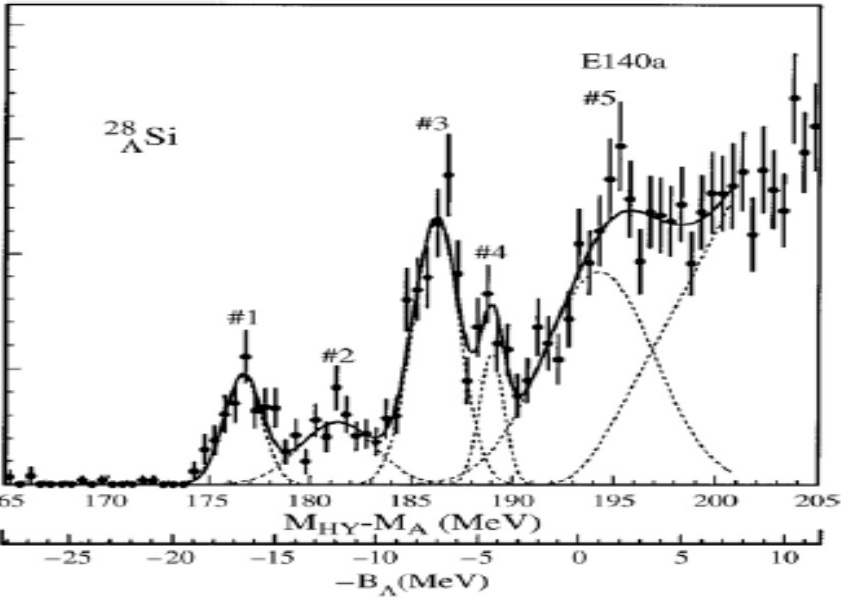
P. Achenbach, Mainz

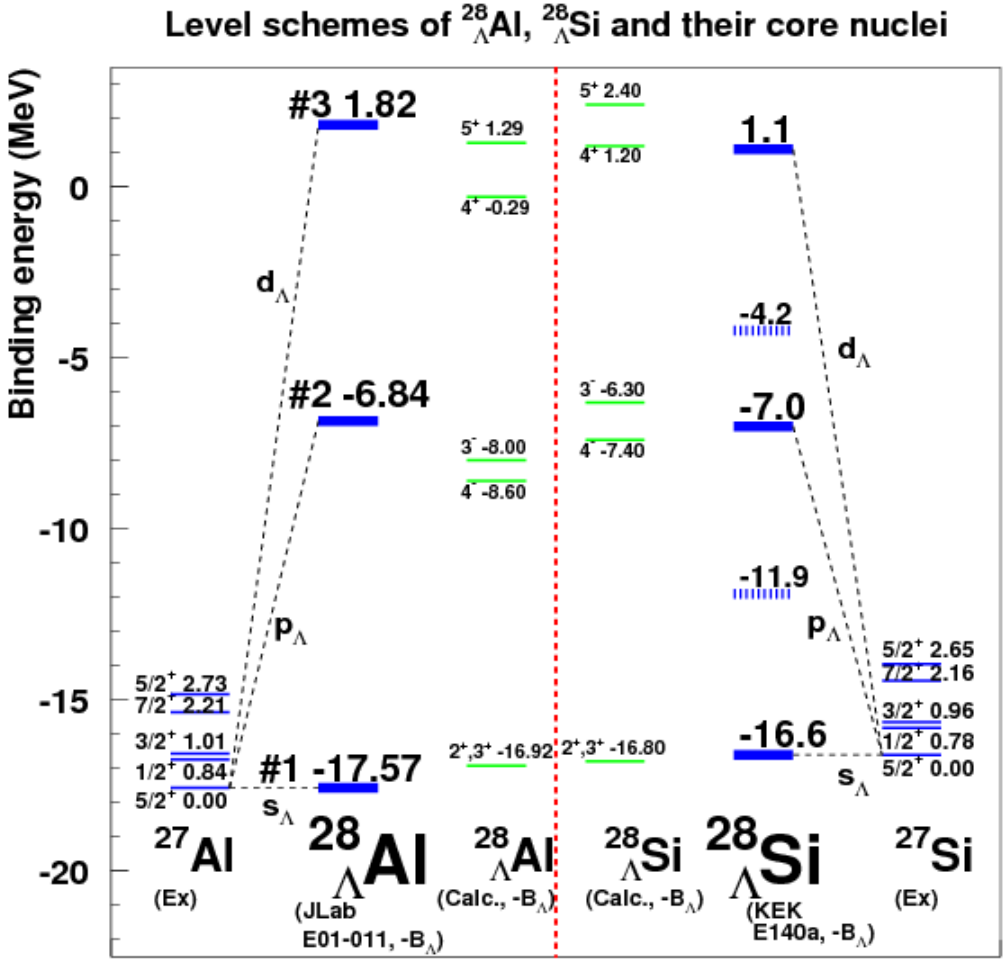
- Only three-body decay modes used for hyperhydrogen
- Systematic errors of > 0.04 MeV not included [D. Davis]
- 155 events for hyperhydrogen, 279 events for hyperhelium

What’s Missing

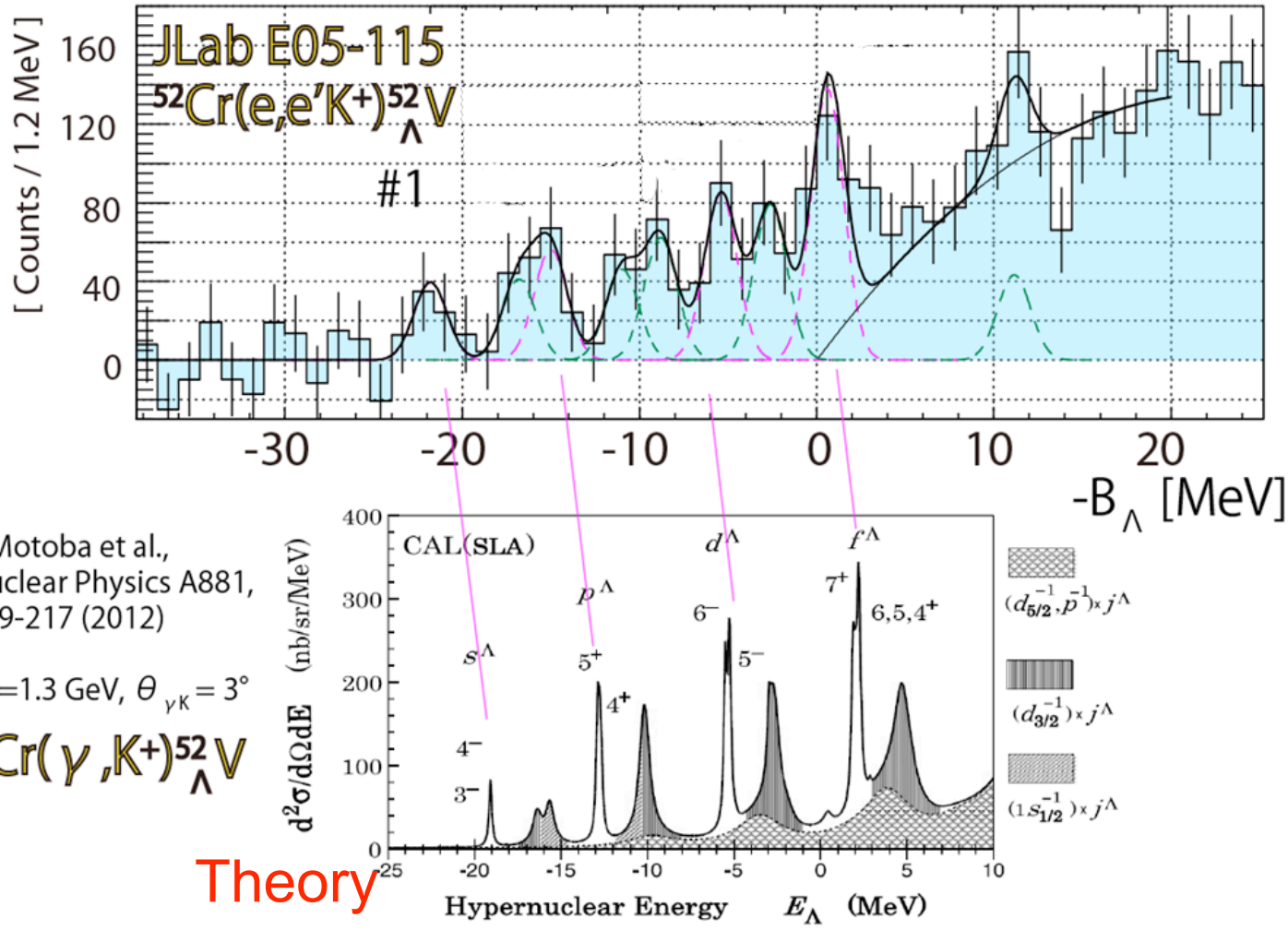
^{28}Si(e,e'K$^+$)$^{28}_{\Lambda}$Al, ^{28}Si(π^+,K$^+$)$^{28}_{\Lambda}$Si





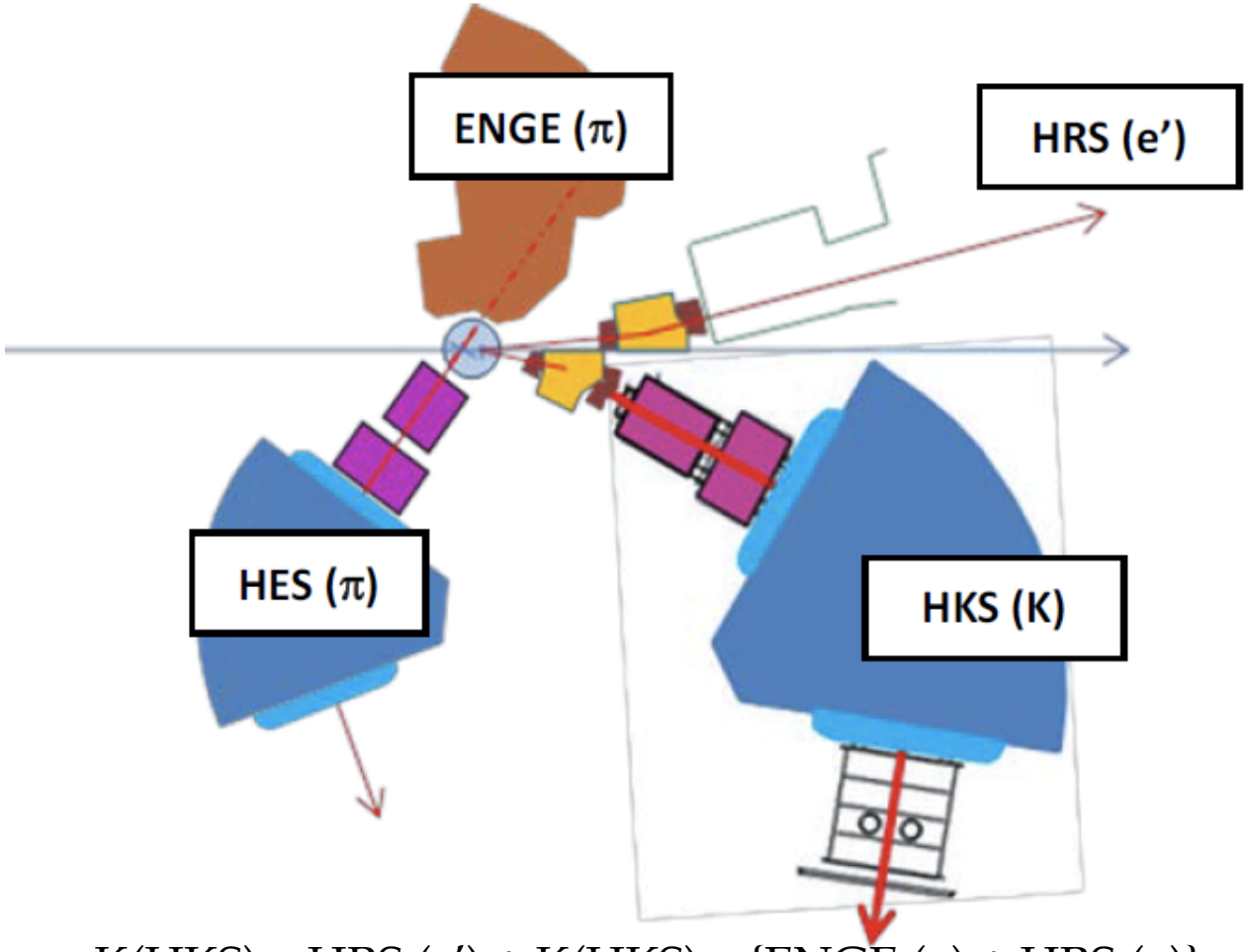


^{52}Cr(e,e'K$^+$)$^{52}_{\Lambda}$V



The Future?

Proposing Setup at JLab 12



K(HKS) x HRS (e') + K(HKS) x {ENGE (π) + HRS (π)}

Only **JLab** : Beam + Spectrometers for (e,e'K^+)

A study with high precision on the electro-production of the Λ and Λ-hypernuclei in the full mass range (PR12-13-002)

Condition #	Beam Energy(MeV)	Beam Current (μA)	Special Request	Target Material	Material Thickness (mg/cm^2)	Est. Beam on time (hours)
1	4523.8	2	2×2 mm^2 raster	CH_2	500	120
2	4523.8	100	Unrastered	^{12}C	100	216
3	4523.8	100	3×3 mm^2 raster	Liq. H_2	283	168
4	4523.8	10	1.5×1.5 mm^2 raster	Liq. D_2	684	72
5	4523.8	10	1.5×1.5 mm^2 raster	Liq. ^4He	500	263
6	4523.8	100	Unrastered	^{40}Ca	100	240
7	4523.8	100	Unrastered	^{44}Ca (^{48}Ca)	100	178
8	4523.8	100	Unrastered	^{48}Ti	100	213
9	4523.8	25	2×2 mm^2 raster	^{208}Pb	100	840
Sub total						2310
10	4523.8	Shared with (e,eK)		^7Li, ^9Be, ^{12}C	53	(1680) Included in the above

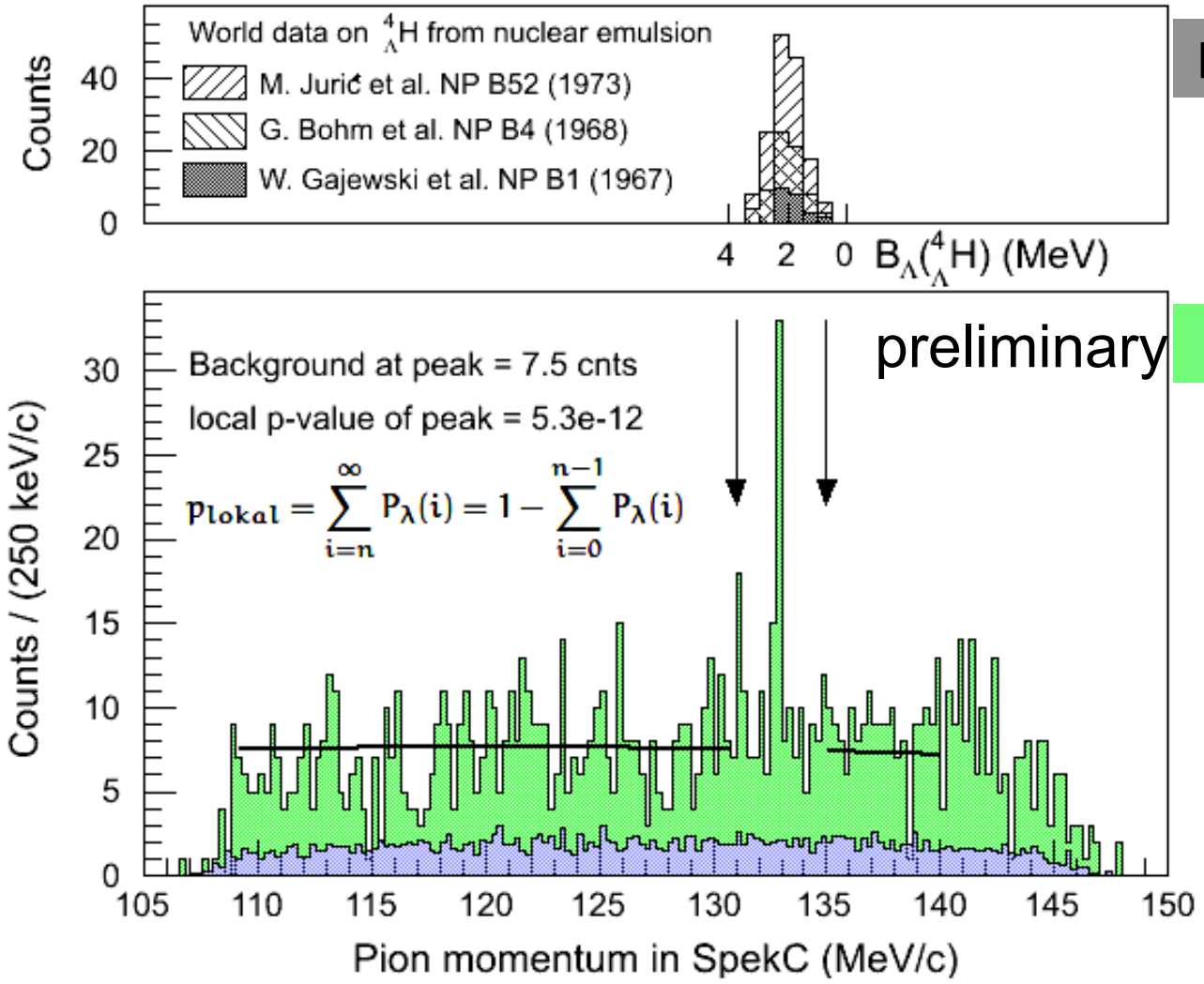
PAC 41 deferred (June 2013):

Issues:

The beam time required for the full program constituted about 100 days. A significant setup time for this experiment requires both resources and significant planning. The PAC felt that the case had not yet been made for such a significant investment, and would encourage, as PAC39 had done, that the proponents work closely with the theory community to identify the most important cases for study. A future proposal should also clearly state the impact of measurements for our understanding of the Λ-N interactions. A careful analysis of how these sets of measurements and their uncertainties constrain nuclear theory would be of value. **A dedicated Workshop focused on these questions could be very helpful.** The PAC needs to see a sense of priority from the proponents. This was missing in the current proposal and in the talks given to the PAC.

Since the Mainz program has not yet produced final results, we are also not in a position to comment on the backgrounds for decay-pion spectroscopy experiments. We believe this is also an important hurdle, as discussed by PAC39, to enable a positive decision for the program at JLab.

Hyperhydrogen peak search



local excess observed inside the hyperhydrogen search region

P. Achenbach, Mainz

Summary of Summer Workshop at JLab (a personal view)

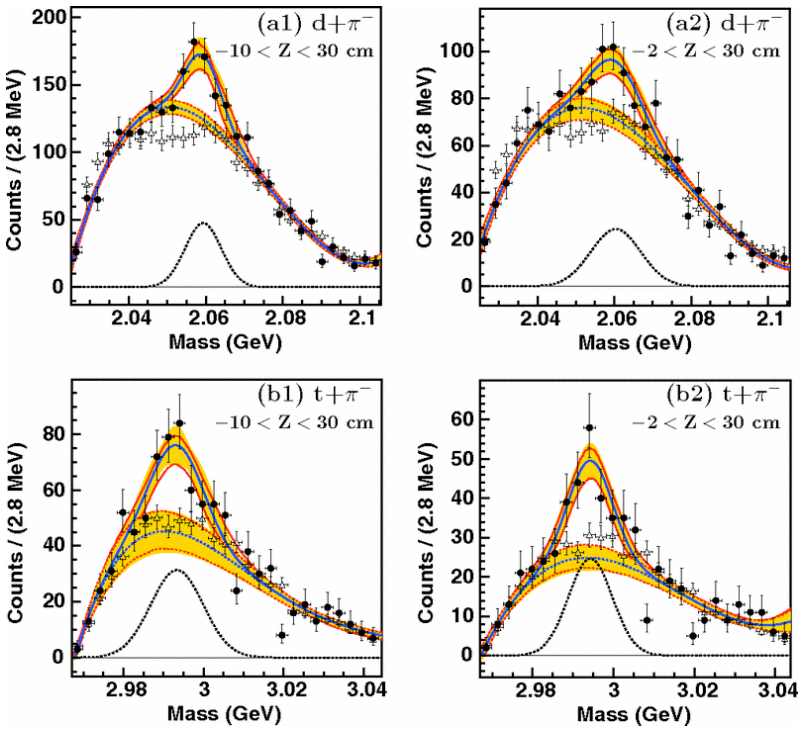
- Someone really should measure Λp
- Remeasure A=3,4 system with <50 keV; MAMI or JLab, whoever can do it best
- Mass dependence of single particle levels all the way to Pb (several targets.)
- Keep theorists on their toes: calculations in support of a proposal need to explore more than just one parameter set.

(e,e’K+) on tritium target?

Search for evidence of $^{3}_{\Lambda}$n by observing d+π⁻ and t+π⁻ final states in the reaction of ^{6}Li+^{12}C at 2A GeV

Phys. Rev. C 88, 041001(R) – Published 10 October 2013

C. Rappold et al. (HypHI Collaboration)



If bound, Λnn could be observed in ^{3}H(e,e'K^{+}).

Current models do not bind Λnn.

1) **Nonexistence of a Λnn bound state,** H. Garcilazo, A. Valcarce, Phys.Rev. C89 (2014) 5, 057001.

2) **Constraints on a possible dineutron state from pionless EFT,** H.W. Hammer, Sebastian König, Phys.Lett. B736 (2014) 208-213.

3) **Three-body structure of the nnΛ system with ΛN-ΣN coupling,** E. Hiyama, S. Ohnishi, B.F. Gibson, Th. A. Rijken, Phys. Rev. C 89 061302 (2014)

4) **Is there a bound $^{3}_{\Lambda}$n?,** Avraham Gal, Humberto Garcilazo, Phys.Lett. B736 (2014) 93-97.

5) **The lightest neutral hypernuclei with strangeness -1 and -2,** Jean-Marc Richard, Qian Wang, Qiang Zhao, arXiv: 1404.3473 [nucl-th].

6) **From Hypernuclei to Hypermatter: a Quantum Monte Carlo Study of Strangeness in Nuclear Structure and Nuclear Astrophysics,** Diego Lonardoni, arXiv:1311.6672 [nucl-th].

Summary

- (e,e'K^+) HY spectroscopy is *now established*.
- Best $^{12}_{\Lambda}$B spectrum with absolute MM calibration
- Binding energy and excitation spectra for several light nuclei.
- *Decay Spectroscopy of electro-produced hypernuclei* has began at MAMI-C. $^{4}_{\Lambda}$H peak was observed with an accuracy of ~100 keV.
- A system combining experience from HKS and Hall A should improve the experimental technique.
- Need solid theoretical justification and prioritization for a new proposal.