27 July 2016

JLab PAC44

An isospin dependence study of the ΛN interaction through the high precision spectroscopy of Λ-hypernuclei with electron beam (update of the conditionally approved C12-15-008)

JLab Hypernuclear Collaboration
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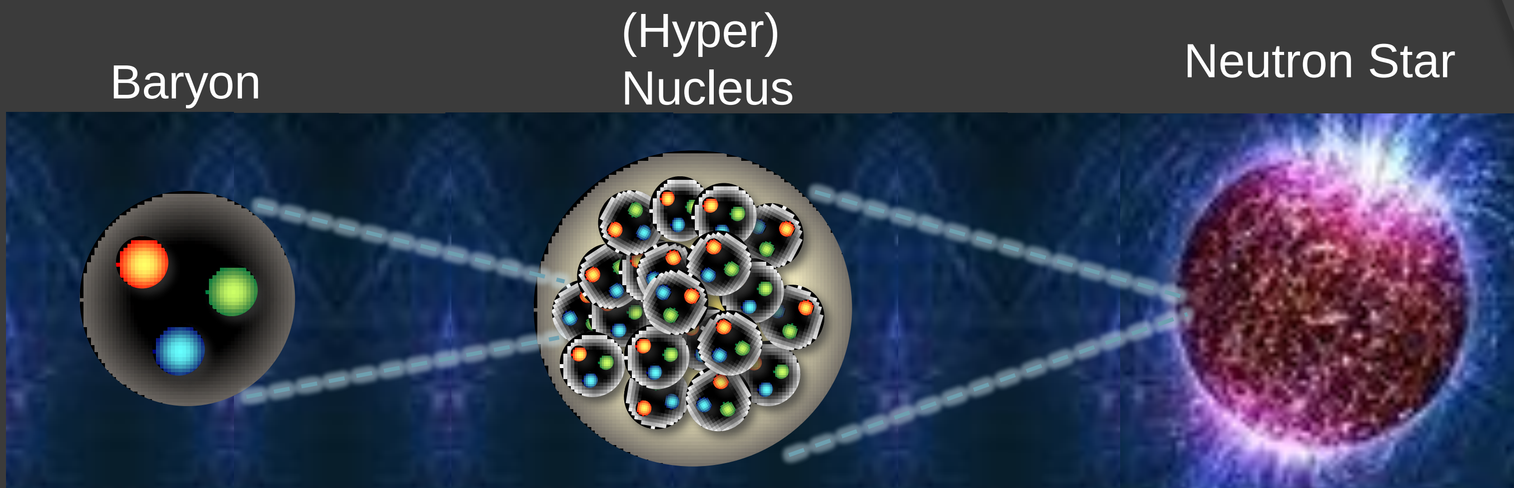
Quantum Many-body System with the Strong Interaction



10^{-15} m 10^{4} m

Spectroscopy of Hypernuclei

NN scat.

Obs. NS 2 $M_\odot$

Hyperon Puzzle

Baryon Interaction

LQCD

Messages from PAC43

Spectroscopy of ${}^{40}_{\Lambda}\mathrm{K}$, ${}^{48}_{\Lambda}\mathrm{K}$ are most compelling physics.

Stronger theoretical connection between Λnn and two M_{sun} NS.

➡ 2nd JLab Hypernuclear Workshop (14,15 March 2016)

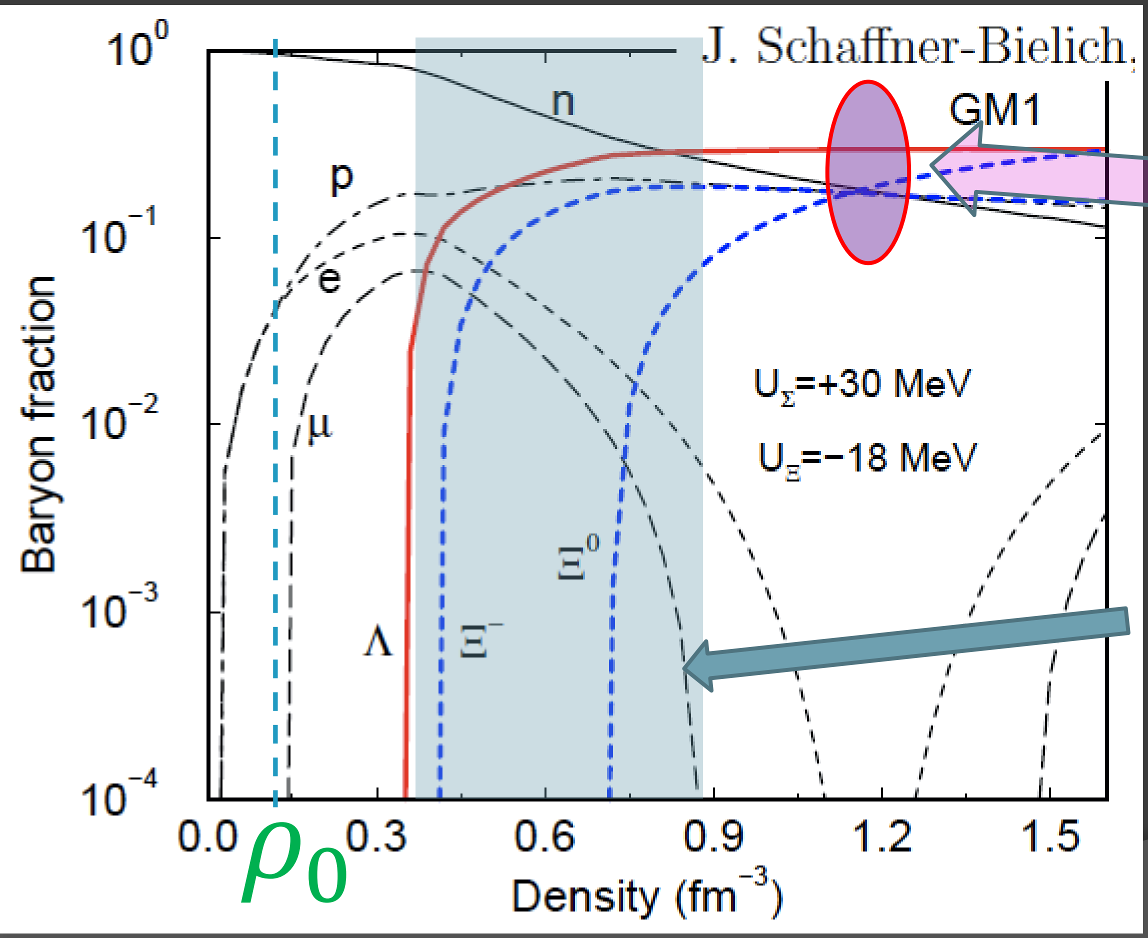
Based on discussions there :

Re-submitted C15-12-008 proposal to PAC44

Neutron star and Strange hadronic matter

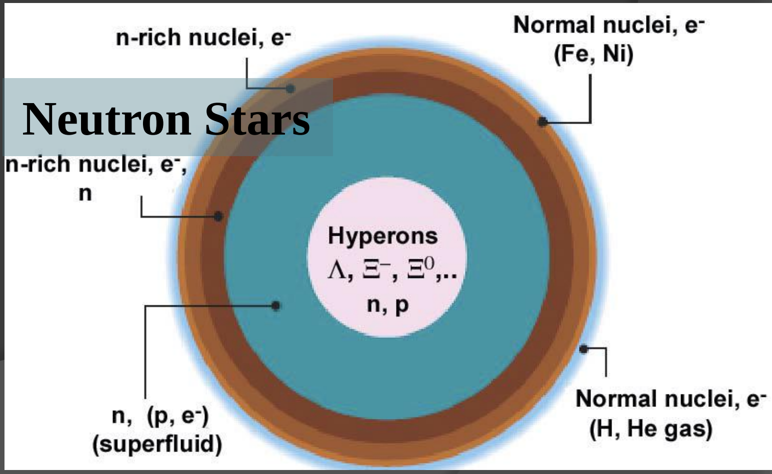
Sym. Nucl. Matter : Limit for size (due to Coulomb force)

Asym. Nucl. Matter : Neutron Stars, Strange Hadronic Matter



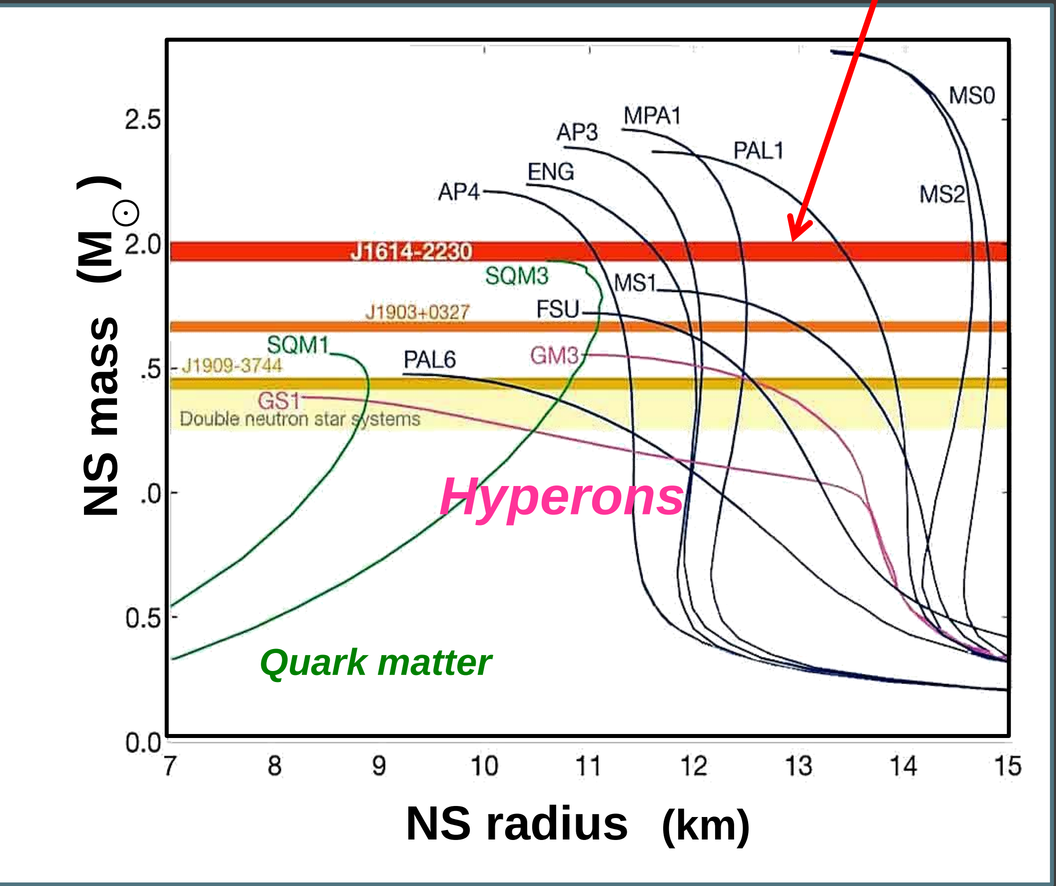
p,n,Λ,Ξ⁰,Ξ⁻

Nu ~ Nd ~ Ns



Hyperon Puzzle

PSR J1614-2230 (2010) 1.97±0.04 M_{sun}
PSR J0348-0432 (2013) 2.01±0.04 M_{sun}



Hyperons should <u>appear</u> at

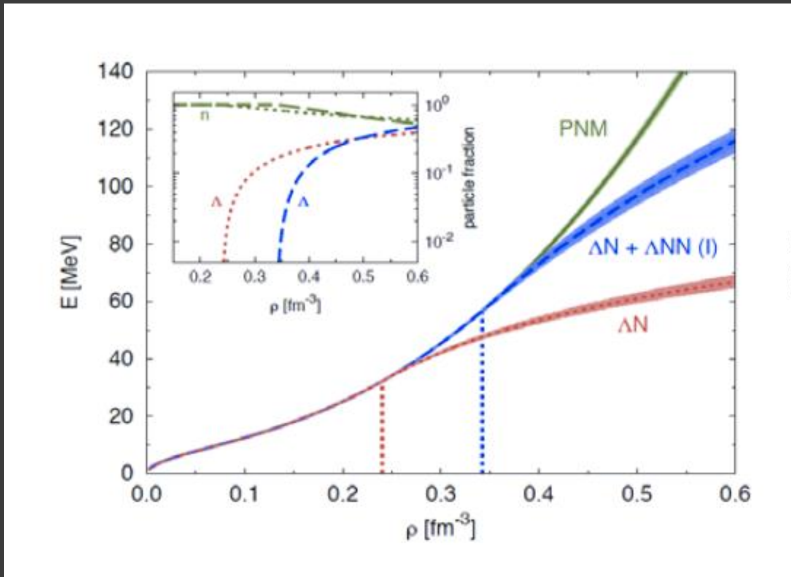
$\rho \sim$2-3 ρ_0

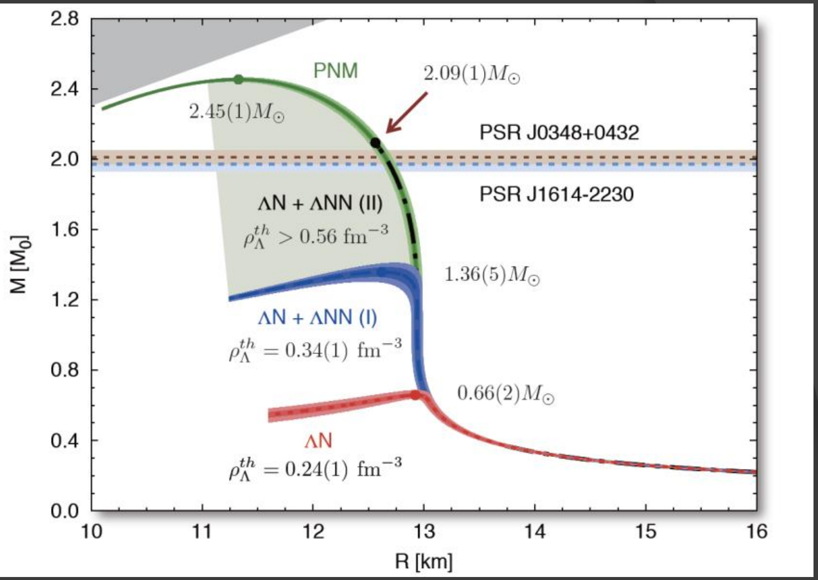
EOS w/hyperons is too soft for 2M_{sun}

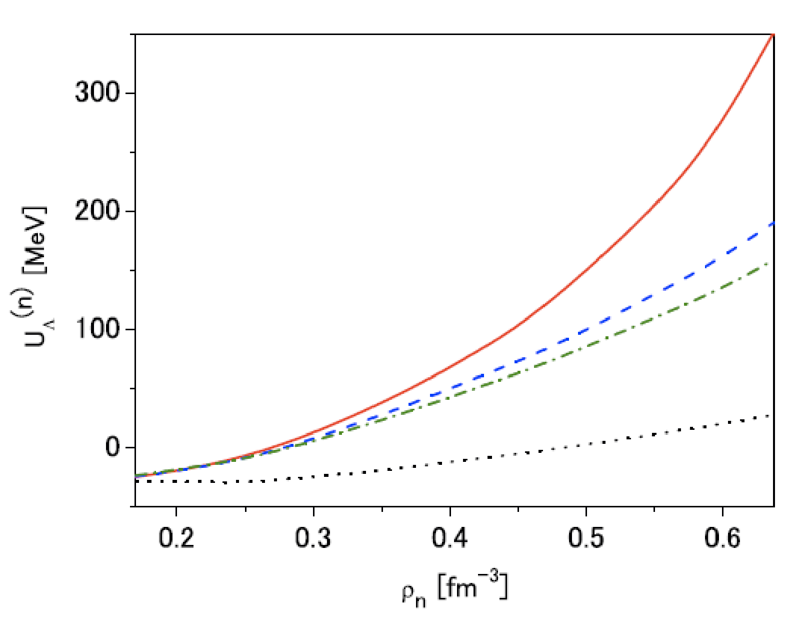
Contradicts observation!

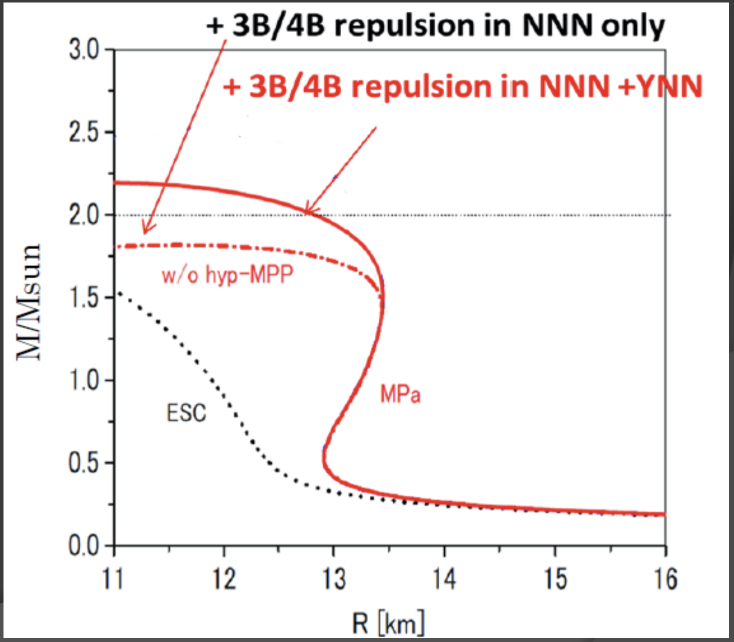
One of most serious problems of nuclear physics

AFDMC by Lonardoni et al. PRL114 (2015) 092301, updated (2016)



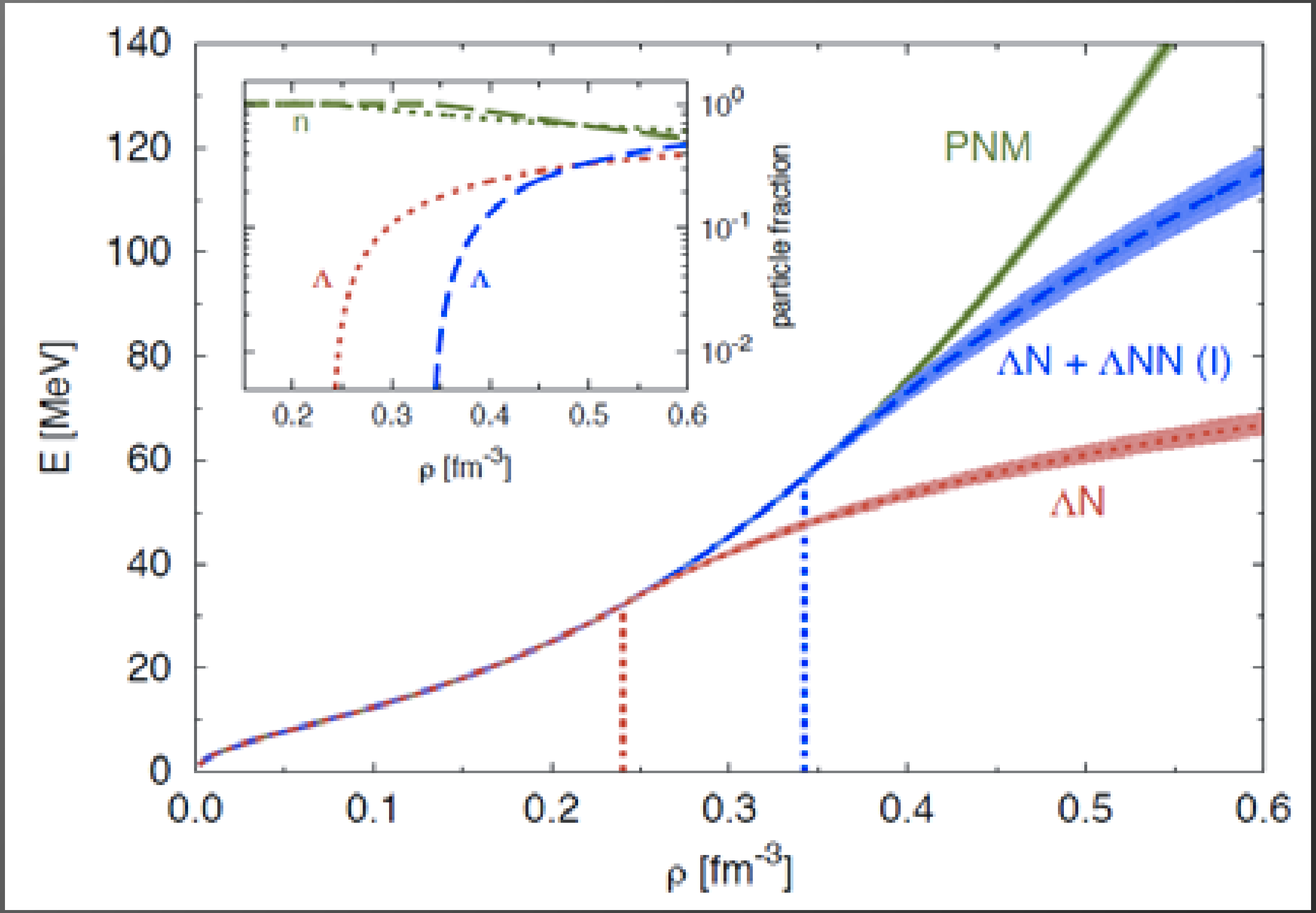






ESC08c + 3B/4B RF : G-Matrix Calc. by Yamamoto et al., PRC 90 (2014) 045805.

NS EOS with hyperon and 3BRF



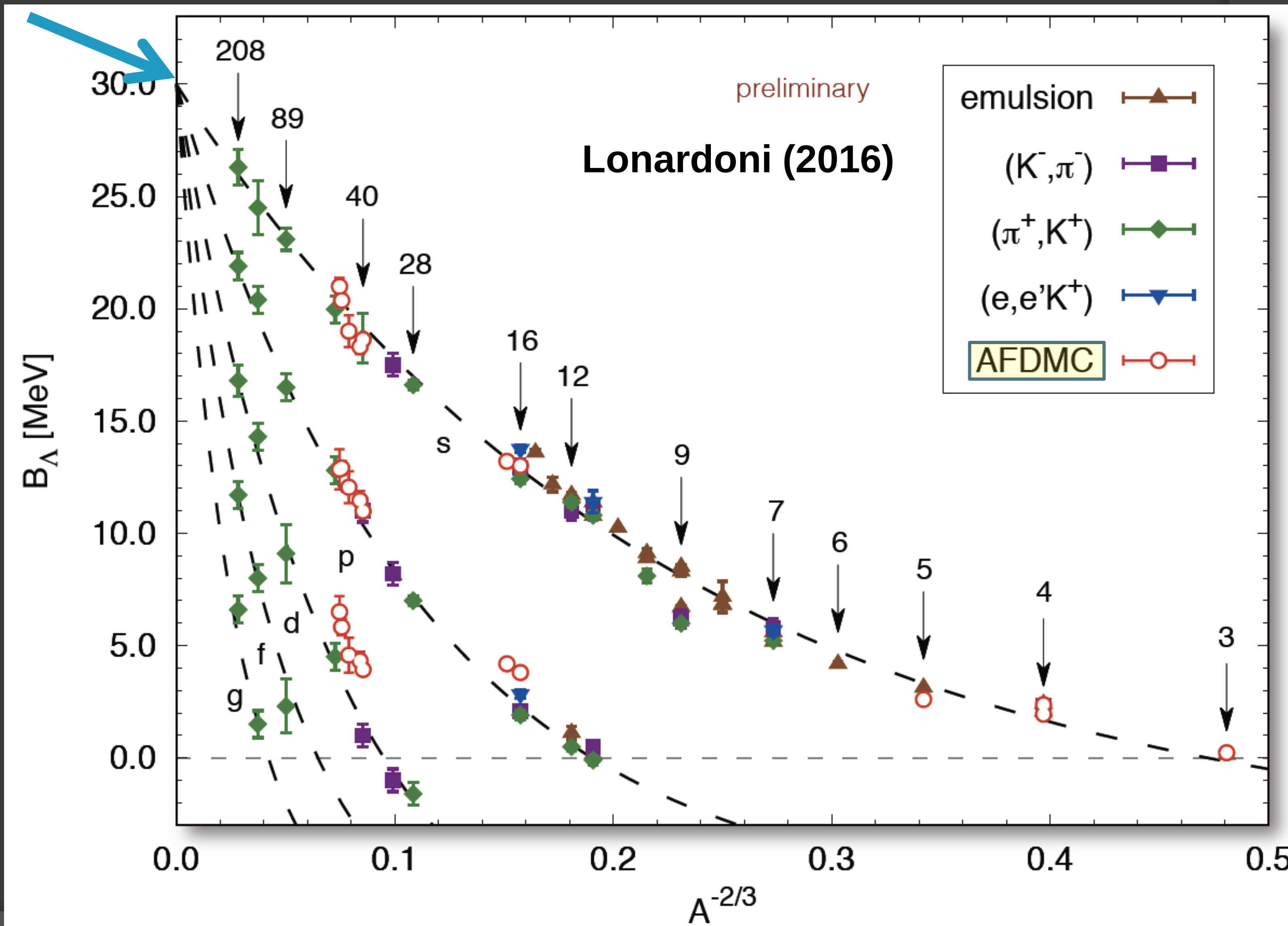
PNM

With 3BRF recover stiffness

With Hyperon too Soft

Mass dependence of B_Λ

Nuclear Matter ($A = \infty$)



Recent progress about ΛN CSB

JLab E05-115 : First B_Λ measurement of ${}^{7}_{\Lambda}$He , HKS-Collaboration

PRL 110, 012502 (2013)

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

2nd paper submitted to PRC
arXiv 1606.09157

CSB for A=7, T=1 system is small

Trigger re-measurements of CSB for A=4 iso-doublet ${}^{4}_{\Lambda}$H, ${}^{4}_{\Lambda}$He

Originally proposed at JLab : PR-10-001, PR-12-13-002
Experimentally performed at MAMI-C

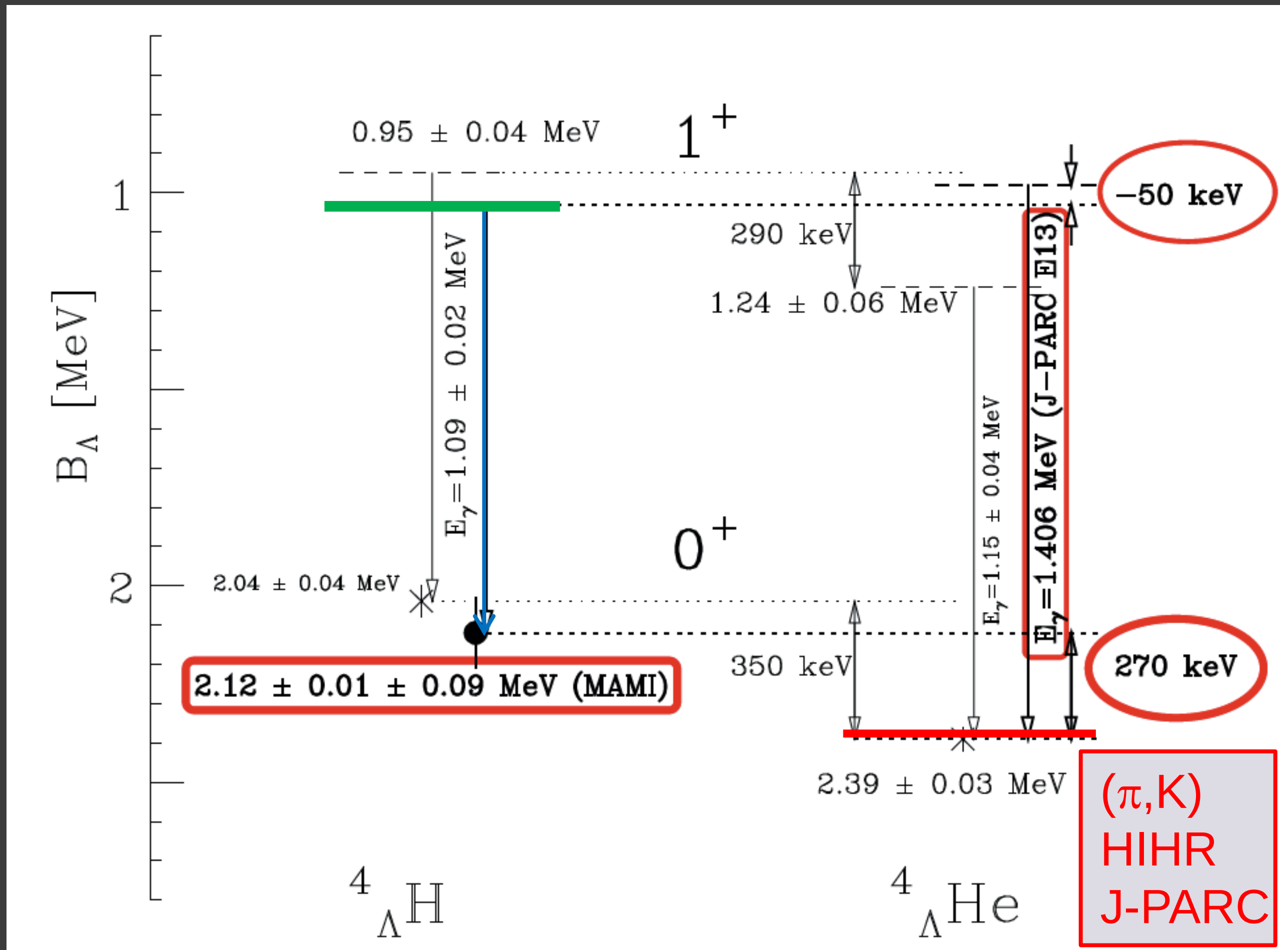
${}^{4}_{\Lambda}$H g.s. measurement by decay π spectroscopy

Gamma-ray measurement at J-PARC E13

Precise determination of Ex(1^+) ${}^{4}_{\Lambda}$He with Hyperball-J

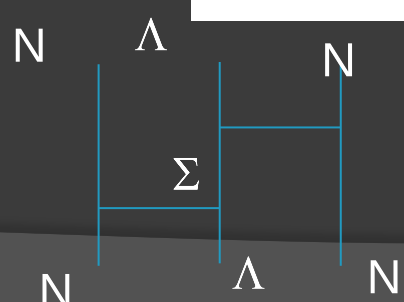
Current status of CSB for A=4 hypernuclei

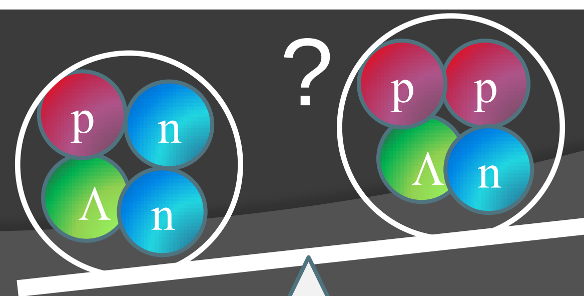
ΛN interaction has large **iso-spin dependence**.



Small CSB

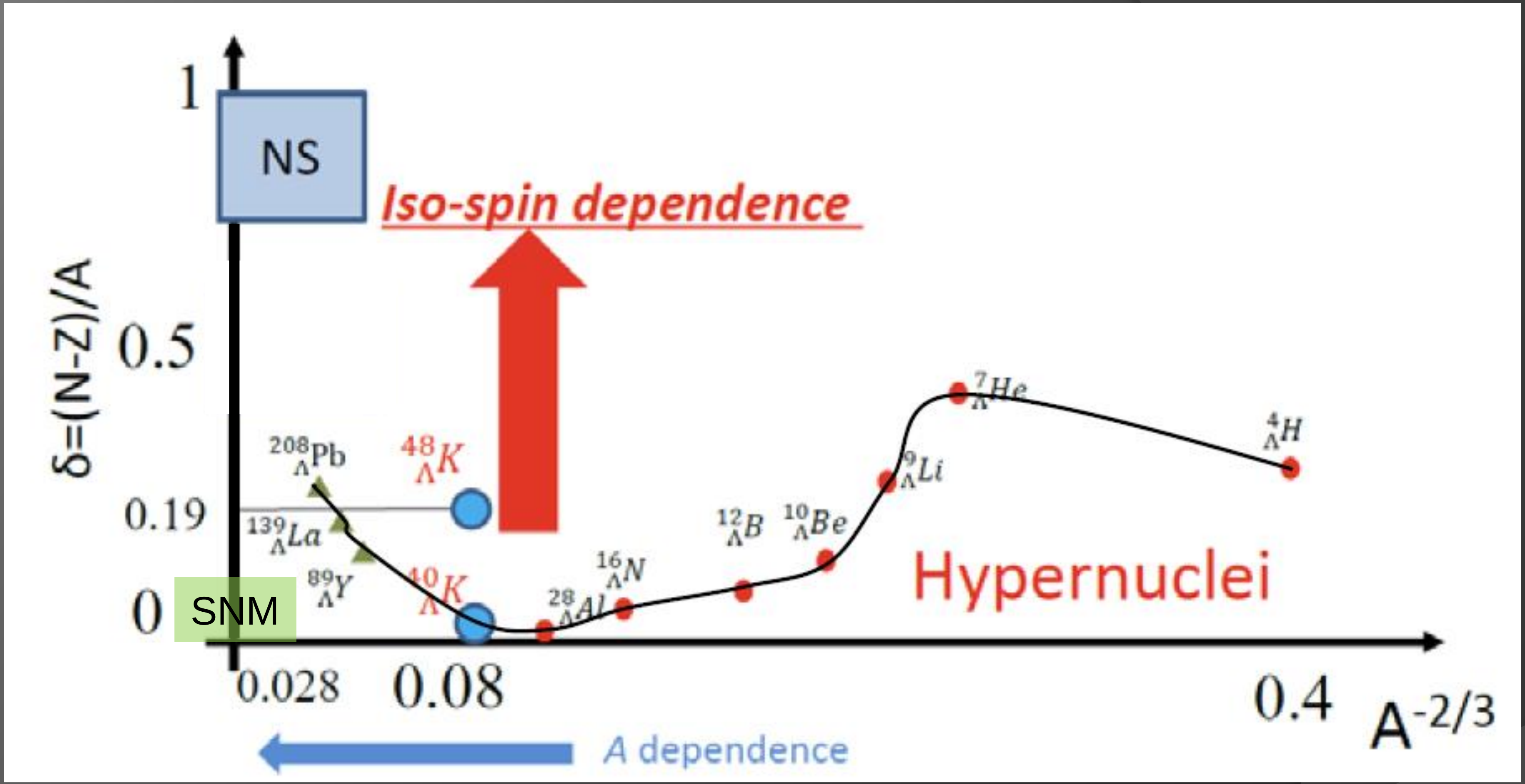
Large CSB





ΛN-ΣN coupling is a key

NS EOS with hyperon and 3BRF

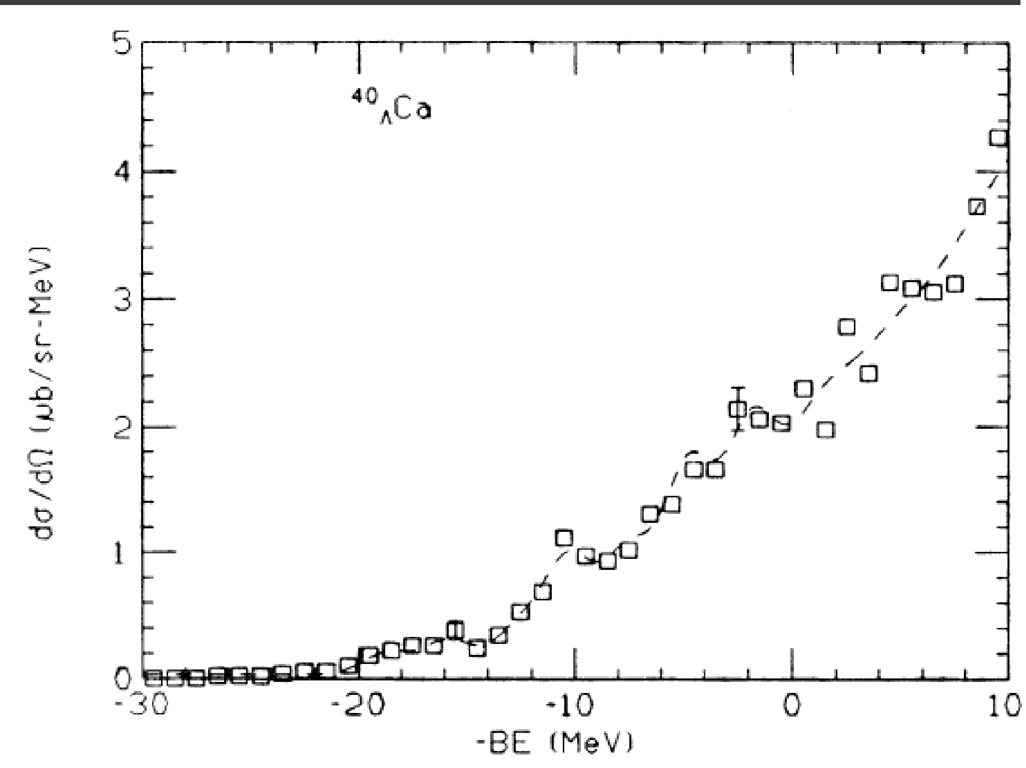


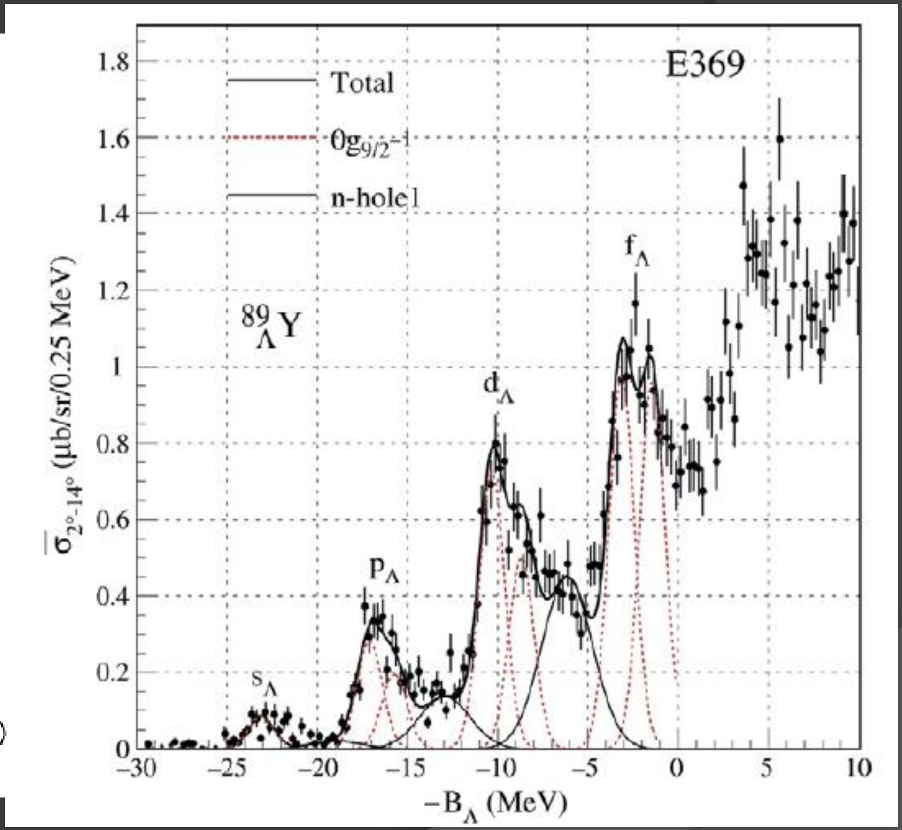
Key issues : *A* Dependence

Iso-spin Dependence of 3BRF

So far, NO experimental inputs for iso-spin dependence in mid-heavy HY

Mid-heavy data from (π,K) exp.

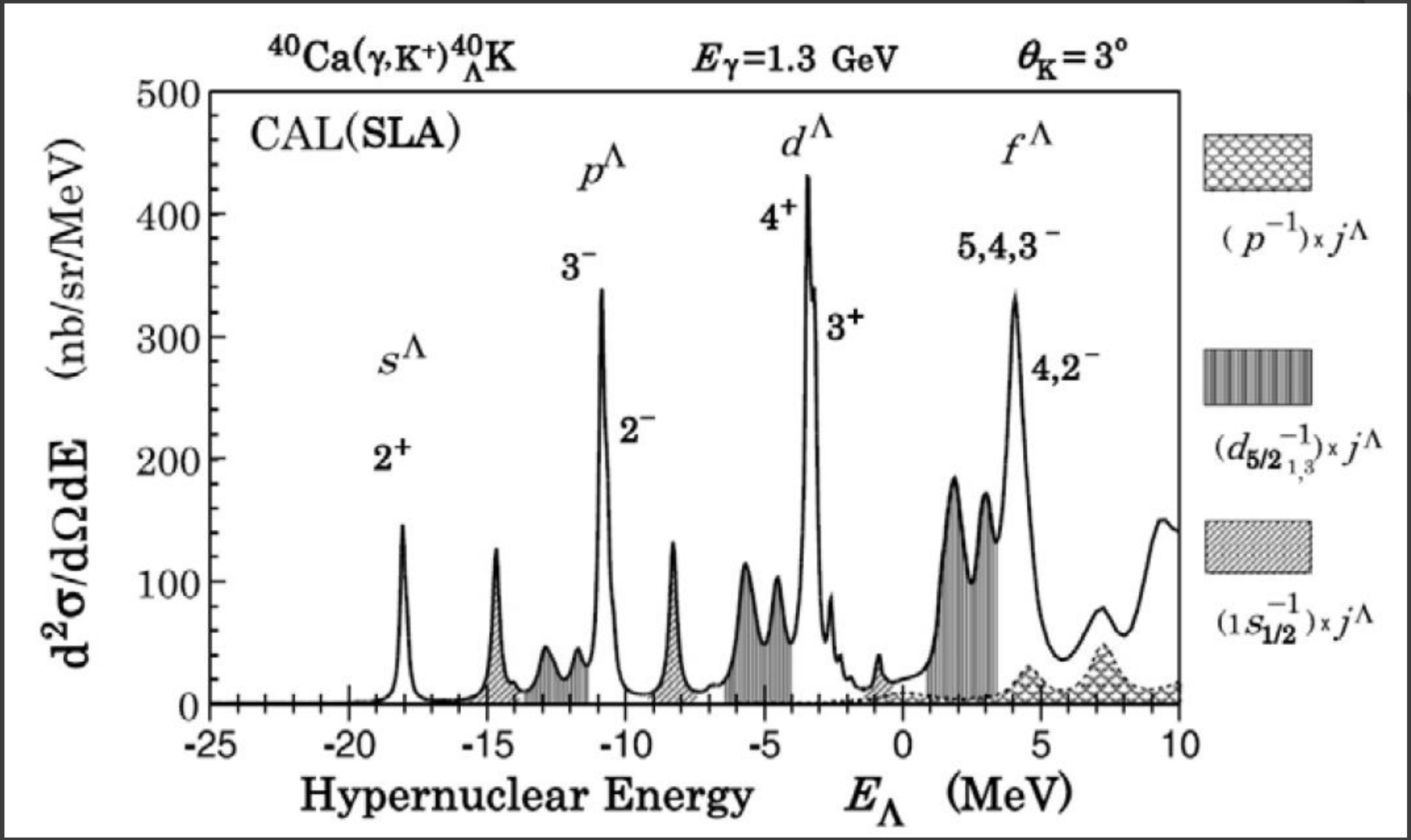




P.H.Pile et al. PRL 20 (1991) 2585.

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

Expected spectrum for $^{40}{}_{\Lambda}K$



0.3 MeV (FHWM) resolution assumed.

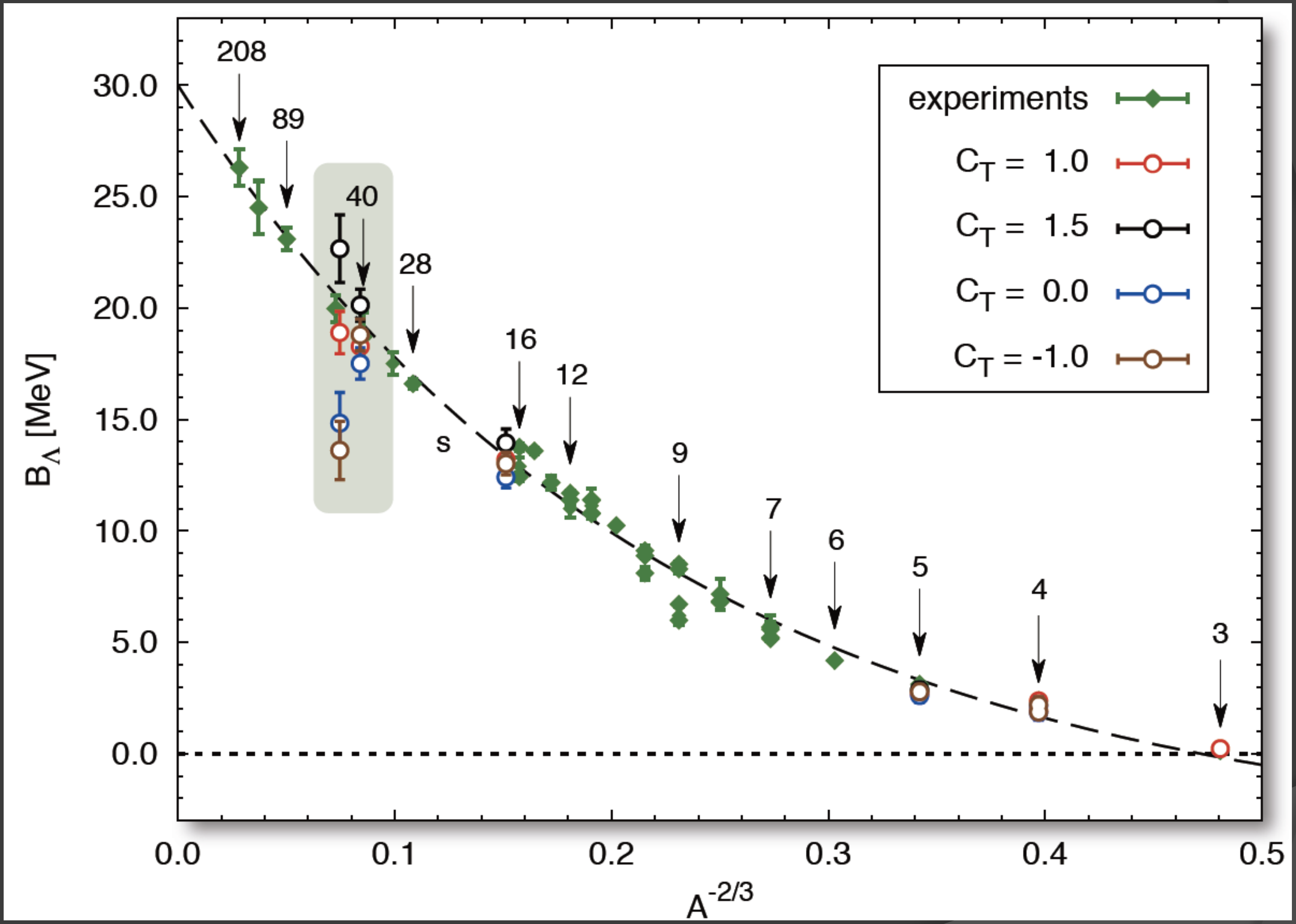
P. Bydzovski et al. NPA881 (2012) 199.

$(e, e'K^+)$ reaction

Reliable absolute energy calibration. — <100 keV accuracy

Excellent energy resolution. — Determination of B_Λ

Λnn/Λnp dependence of B_Λ



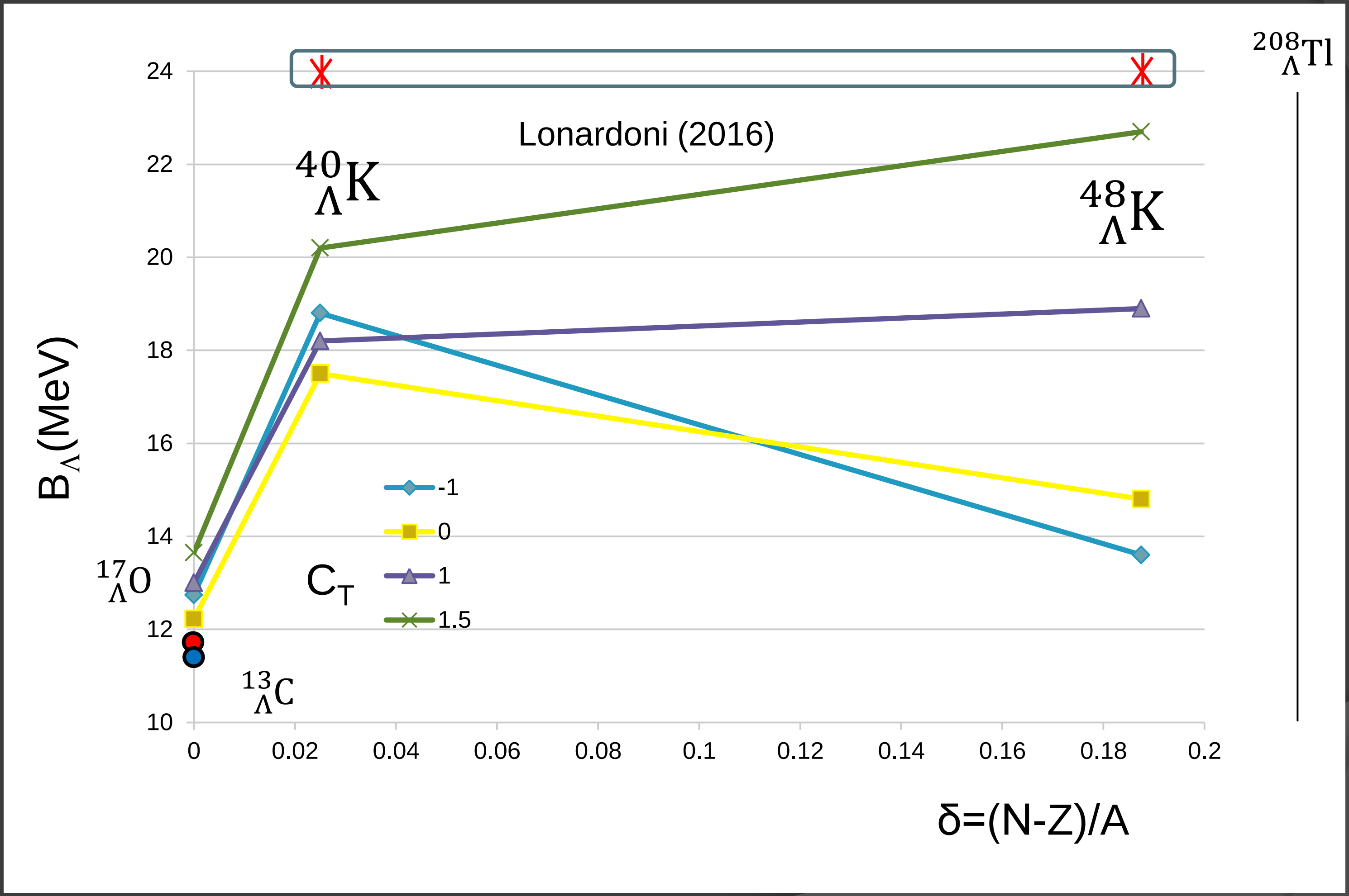
Introduced ΛNN potential

$$\boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j = -3P^{\mathrm{T}=0} + C_{\mathrm{T}}\, P^{\mathrm{T}=1}$$

C_T gauges strength and sign of Λnn to Λnp 3B force.

Λnn/Λnp dependence of B_Λ

Could be determined with an accuracy of <100keV at JLab



Targets availability

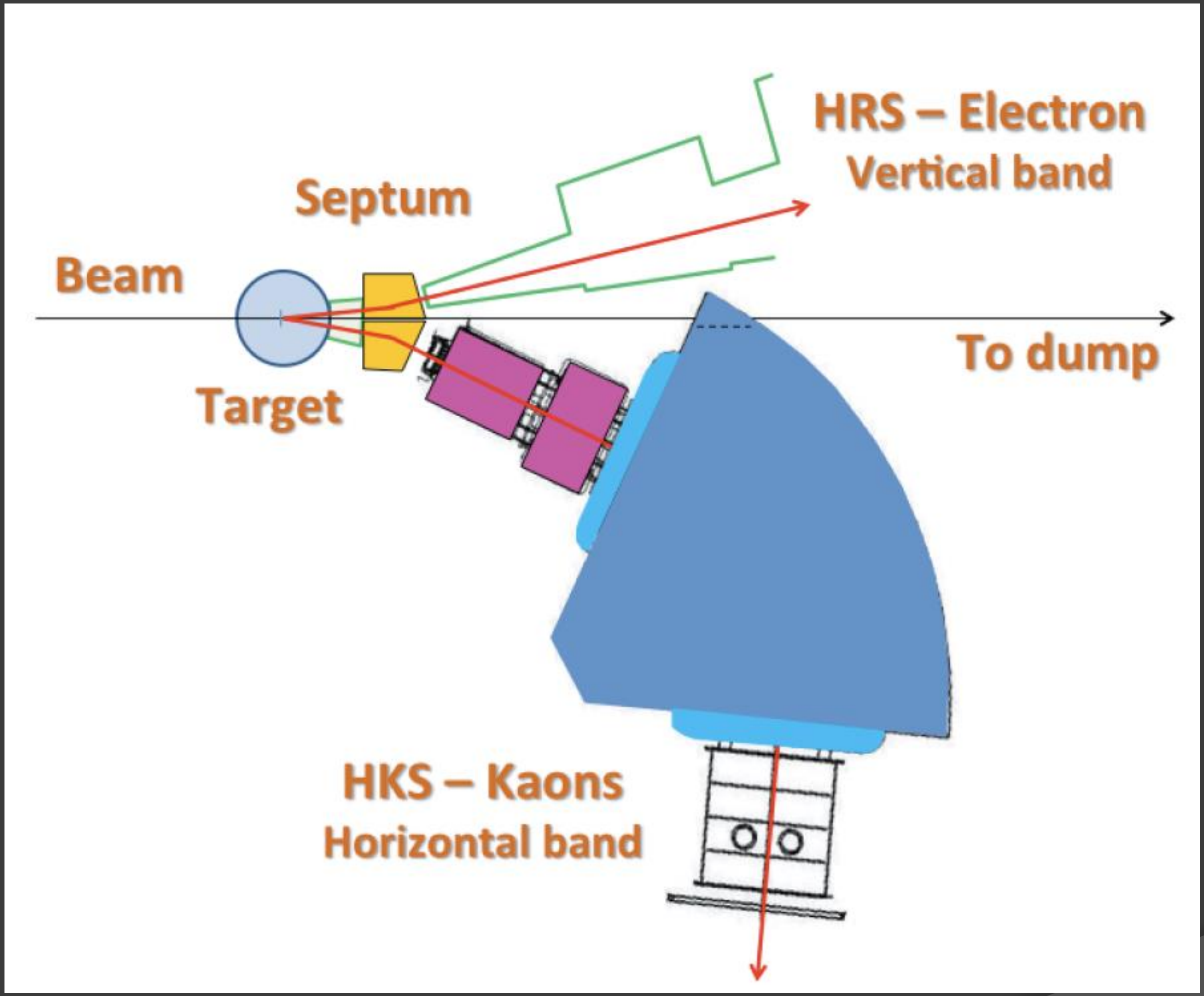
JLab has a 800mg/cm^2 thick ^{48}Ca target for CREX exp,
but it was oxidized and surface condition is not good.
Furthermore, it is too thick for our experiment.
(Eloss effects are 500keV for both e' and K^+)

Making a new 100mg/cm^2 ^{48}Ca costs roughly $50K.

^{40}Ca is one order less expensive.

	Li	C	Ca	Pb
Melting Point ($^\circ C$)	181	3642	**842**	323
Heat Cond. (W/(m*K))	85	120	**201**	35

Proposed Setup



K(HKS) x HRS (e')

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

Beamtime estimation

	Beam Current (μA)	Target Thick (mg/cm^2)	Assumed CS (nb/sr)	Expected Yield(/h)	Beam Time (h) For 200ev.	BG (/MeV/h) for 250MHz	S/N
$^{40}_{\Lambda}K$	50	50	10	0.9	230	0.43	4.0
$^{48}_{\Lambda}K$	50	50	10	0.7	278	0.42	3.5
Calib.					147		
Total					655		

655 h ≈ 28 PAC days

Absolute energy calibration is possible with p(e,e'K$^+$)Λ, Σ^0.
Not for (π,K) or (K,π) due to lack of neutron target.

High resolution and reliable calibration are keys.

precision *accuracy*

Summary

PAC43 suggested that measurements of ${}^{40}_{\Lambda}\mathrm{K}$, ${}^{48}_{\Lambda}\mathrm{K}$ proposal should be re-submitted with more theoretical works to bridge ΛNN interaction and hyperon puzzle.

Theoretical efforts with AFDMC and AMD are in progress to predict B_{Λ} reliable medium heavy hypernuclei. Based on these efforts, ΛNN interaction model can be applied to NS to solve the hyperon puzzle.

Recent experiments on ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$ show Charge Symmetry for ΛN is Broken for A=4. Isospin dependence for medium-heavy hypernuclei should be experimentally studied.

Based on established techniques and spectrometers at JLab, measurement of B_{Λ} for ${}^{40}_{\Lambda}\mathrm{K}$, ${}^{48}_{\Lambda}\mathrm{K}$ with a precision of <100 keV can be achievable with a reasonable beamtime (<30 PAC days including calibrations).

Will provide the first data for isospin dependence of ΛNN force.

Backup

Responses to Tech. Comments

6. The PAC-43 version of the proposal used numerous extended gas targets, this version appears to have removed them in favor of running with solid targets. Nevertheless, the revised proposal makes reference to accommodating "extended targets" in sections 3.1, 3.5, 3.6, and to "gaseous targets" in section 4.1. This inconsistency needs resolution.

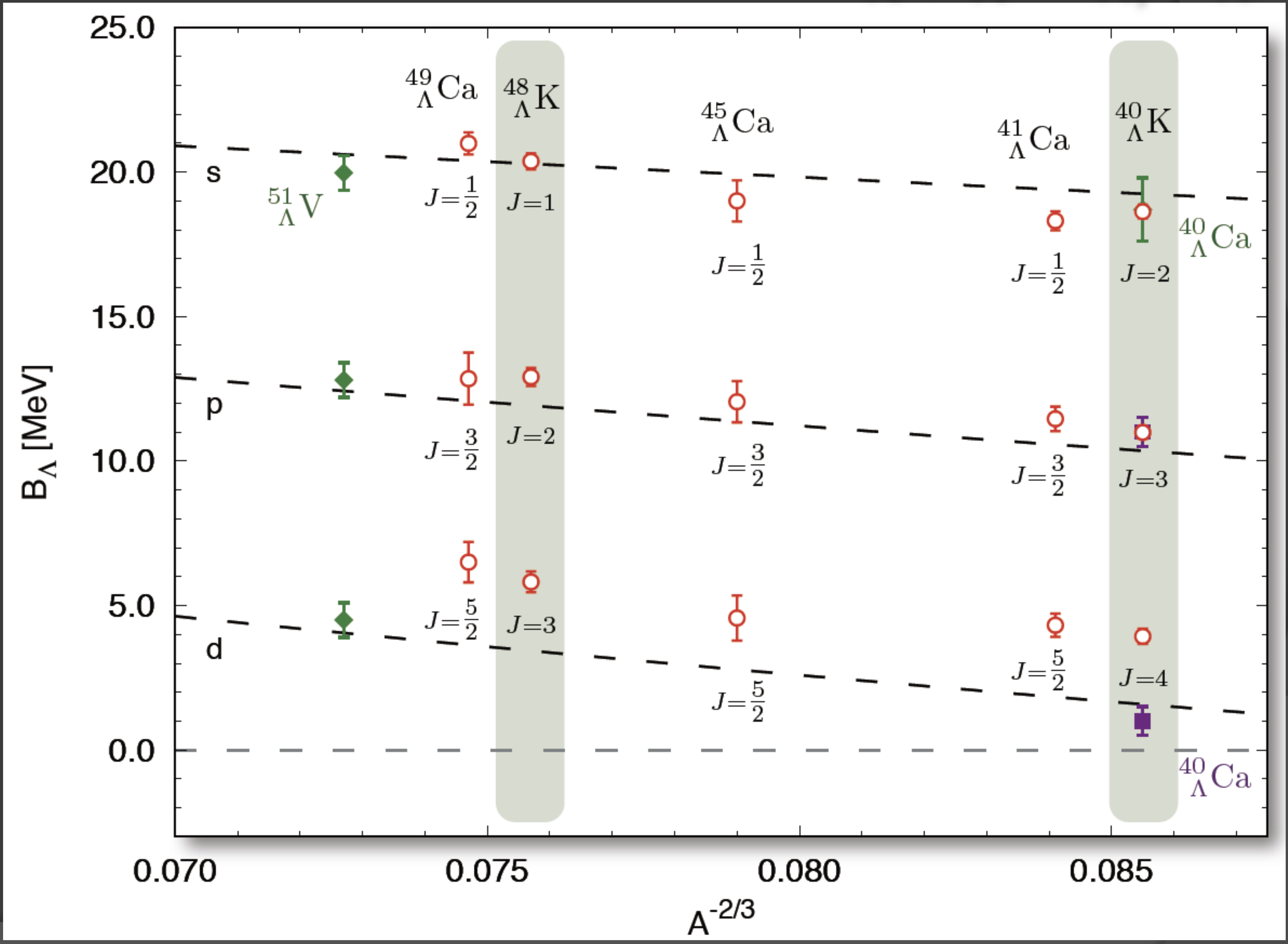
We will design vacuum chamber and septum magnets to accommodate gas and cryogenic targets for possible other hypernuclear programs and thus Monte Carlo study was performed for such targets, but the proposed C12-15-008 concentrates on ^{40}Ca, ^{48}Ca and solids targets. Therefore effect of DZ resolution does not significantly affect the proposed program and discussion about them in the proposal is redundant.

These effects should be discussed separately in a possible future proposal.

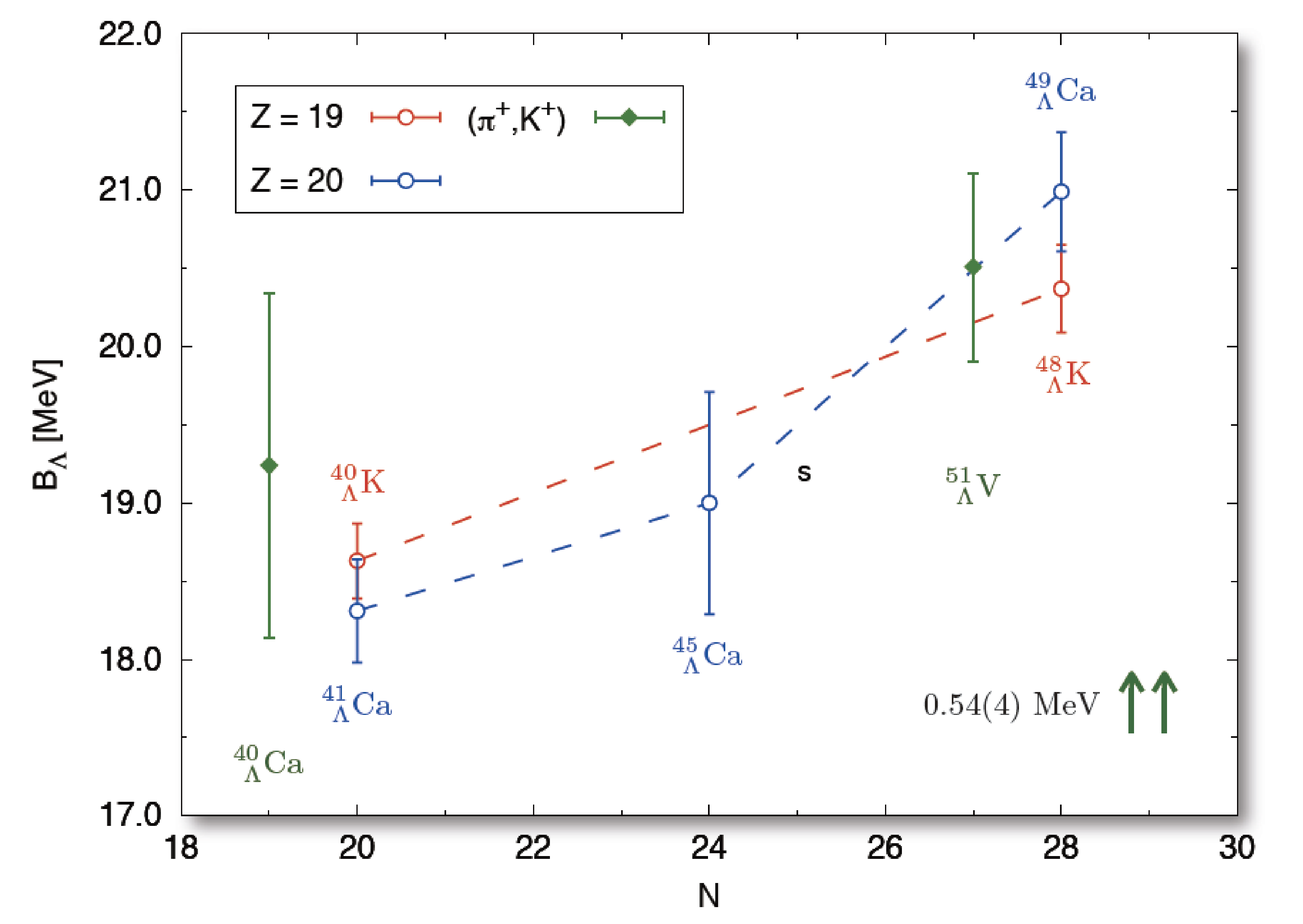
7. Obtaining good missing mass resolution with extended targets relies on the ability of the HRS with a septum magnet to determine the z position of the interaction. The Z resolution was simulated with GEANT. While the septum magnet for this experiment will be new, previous experience using other septa with HRS spectrometers could help to validate this simulation.

We plan to compare GEANT simulation result and our experience using septa with HRS obtained in Hall-A and its result will be feed-backed to the mechanical design of the septum magnets.

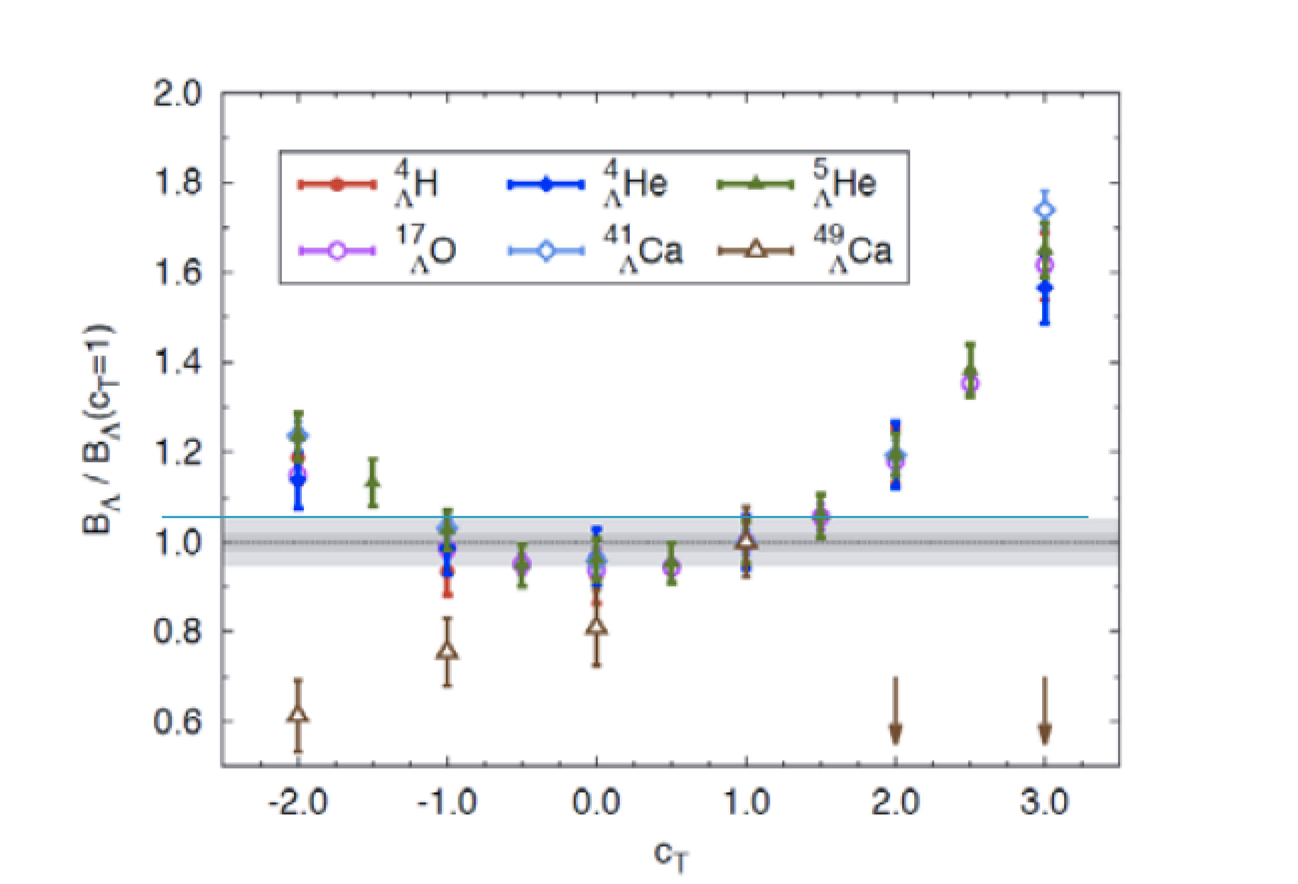
Mass dependence of $B_\Lambda(s_\Lambda, p_\Lambda, d_\Lambda)$



N dependence of B_Λ(gs)



$\Lambda nn/\Lambda np$ dependence of B_Λ



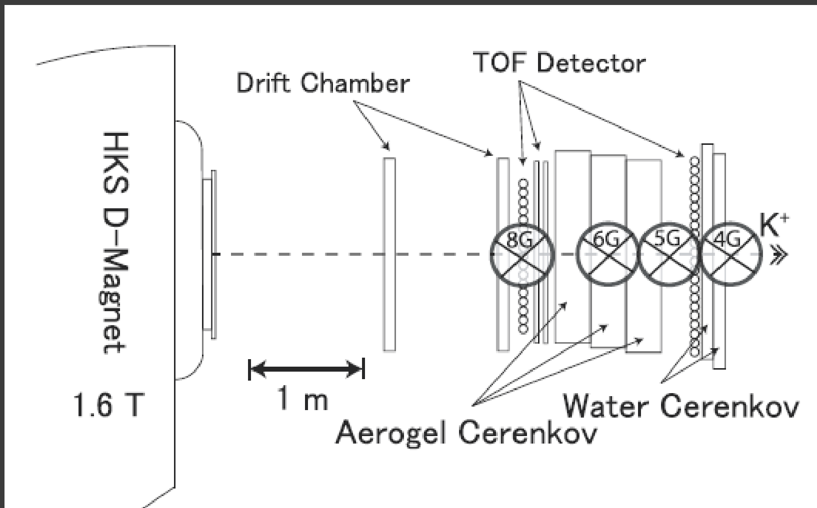
Presented at PAC43

Figure 2-10: Λ separation energies normalized with respect to the $C_T = 1$ case as a function of C_T. Grey bands represent the 2% and 5% variations of the ratio B_Λ/B_Λ ($C_T = 1$). Brown vertical arrows indicate the results for ^{49}Ca in the case of $C_T = 2$ and $C_T = 3$, outside the scale of the plot.

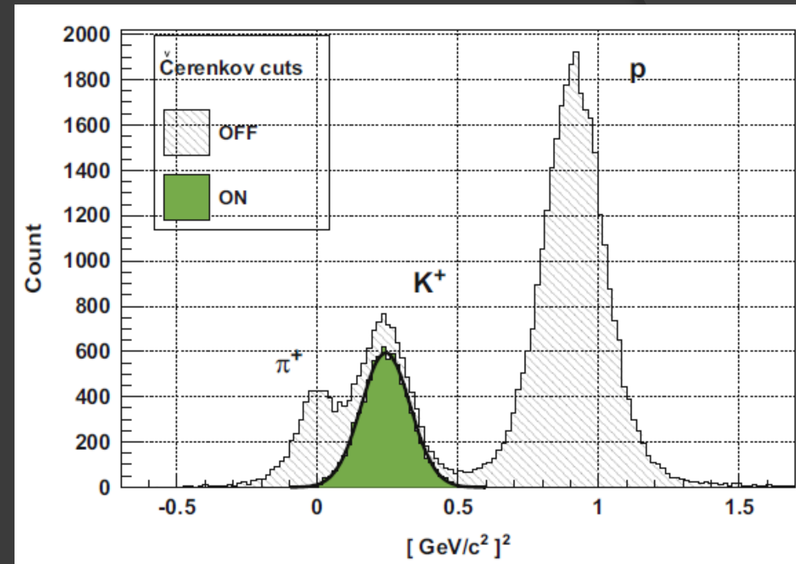
Breakdown of the requested beamtime

Target and objective hypernucleus	Beam current (μA)	Target thickness (mg/cm^2)	Assumed cross section (nb/sr)	Expected Yield (/hour)	Num. of events	Req. beamtime (hours)	B.G. Rate (/MeV/h)	S/N (±1σ)	Comments
CH_2	2	500	200	19	1000	54	0.05	252	Calibration
$^{6,7}Li$	50	100	10	5.4	150	28	1.3	4.9	Calibration
^{9}Be	100	100	10	36	300	9	4.7	8.8	Calibration
$^{10,11}B$	25	100	10	16	150	19	0.29	33	Calibration
^{12}C	100	100	100	54	2000	37	4.4	17	Calibration
Subtotal for calibration targets						**147**			
^{40}Ca ($^{40}_{\Lambda}K$)	50	50	10	0.9	200	230	0.43	4.0	
^{48}Ca ($^{48}_{\Lambda}K$)	50	50	10	0.7	200	278	0.42	3.5	
Subtotal for heavier targets						**508**			
Total						**655**			

Well established K+ identification



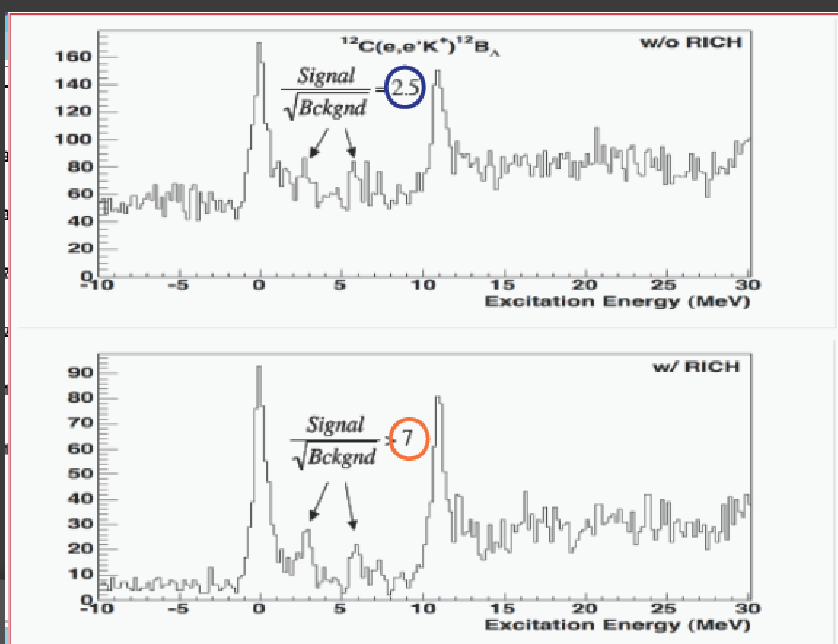
T.Gogami et al., NIM A729 (2013) 816.



Rejection power $(\pi^+) > 4.7 \times 10^{-4}$

$(p) > 1.9 \times 10^{-4}$

for 1.2 GeV/c



Further improvement is possible by using RICH used in Hall-A HY for K+ with higher momentum

M. Iodice, et al., Nucl. Instrum. Methods A 553 (2005) 231.
F. Garibaldi, et al., Nucl. Instrum. Methods A 502 (2003) 117.
F. Cusanno, et al., Nucl. Instrum. Methods A 502 (2003) 251.