Jlab Hypernuclear Collaboration Meeting

07 Dec. 2021

Opening & Introduction

SATOSHI N. NAKAMURA

TOHOKU UNIVERSITY

COVID-19 prevents our on-site meeting at JLab.

No visit to JLab for us after Feb. 2020.

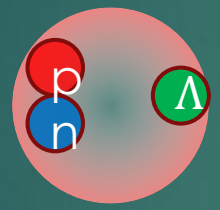
We have more frequent on-line meetings now.

It is time to move forward !

Current problems of Λ hypernuclei

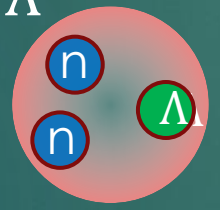
Hypertriton Puzzle

Shallow bound
Short lifetime

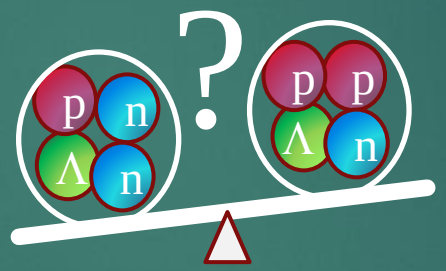


Bound?
Resonance?
Not Exist?

$^{3}_{\Lambda}n$ Puzzle



CSB of Λ Hypernuclei



Hyperon Puzzle

Why massive
NS exists?

A=3

10^{-15} m

$A\sim10^{57}$

10^{4} m

Current problems of Λ hypernuclei

New method to study nuclear shape $^{27}_{\Lambda}\mathrm{Mg}$

Hypertriton Puzzle

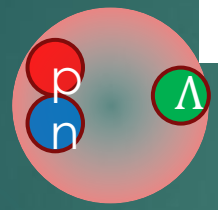
MAMI

JLab E12-19-002

Shallow bound
Short lifetime

J-PARC

ELPH

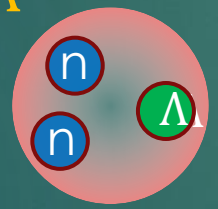


$^{3}_{\Lambda}n$ Puzzle

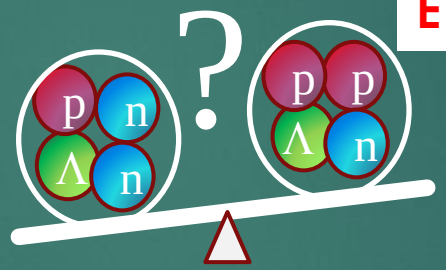
GSI

Bound?
Resonance?
Not Exist?

JLab E12-17-003



CSB of Λ Hypernuclei



JLab E12-15-008 E12-20-013

Hyperon Puzzle

Why massive NS exists?

Recent astronomical observations

$A=3$

10^{-15} m

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J-PARC HIHR

Current problems of Λ hypernuclei

First Session 7th

New method to study nuclear shape $^{27}_{\Lambda}$Mg

JLab E12-19-002

MAMI

Shallow bound
Short lifetime

Hypertriton Puzzle

J-PARC

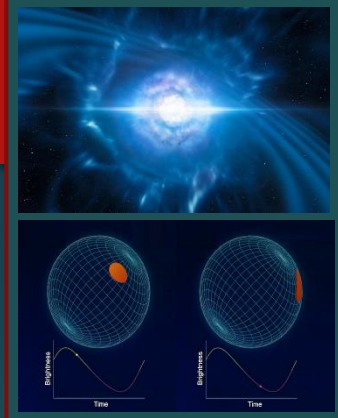
ELPH

CSB of Λ Hypernuclei

JLab E12-15-008 E12-20-013

Hyperon Puzzle

Why massive NS exists?



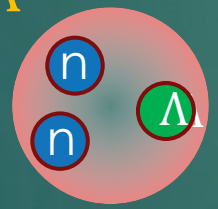
Recent astronomical observations

Session 9th : Hall-C option

$^{3}_{\Lambda}n$ Puzzle

GSI

Bound?
Resonance?
Not Exist?



JLab E12-17-003

A=3

10^{-15} m

Second Session 8th : Engineering Info. Discussion

J-PARC HIHR

Second Session 7th : Hall A/C current and future Preparation status of Experiment

Current problems of Λ hypernuclei

First Session 7th → **New method to study nuclear shape $^{27}_{\Lambda}$Mg**

JLab E12-19-002

MAMI

Shallow bound
Short lifetime

Hypertriton Puzzle

J-PARC

ELPH

CSB of Λ Hypernuclei

JLab E12-15-008
E12-20-013

Hyperon Puzzle

$^{3}_{\Lambda}n$ Puzzle

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Resonance?
Not Exist?

JLab E12-17-003

A=3

10^{-15} m

10^{4} m

J-PARC HIHR

S.N. Nakamura (Tohoku Univ.)	Opening + Introduction
	Physics overview of new experiment (A = 40, 48)
F. Garibldi (INFN)	Physics overview of new experiment (A = 208)
T. Gogami (Kyoto Univ.)	Physics overview of new experiment (A = 3, 4)
K. Okuyama (Tohoku Univ.)	Hypernuclear study from ^{27}Al (A = 27)

Recent astronomical observations

Current problems of Λ hypernuclei

New method to study nuclear shape $^{27}_{\Lambda}\mathrm{Mg}$

Hypertriton Puzzle

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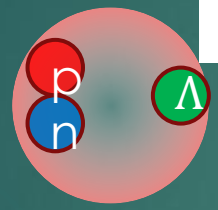
JLab E12-19-002

J-PARC

ELPH



$^{3}_{\Lambda}n$ Puzzle

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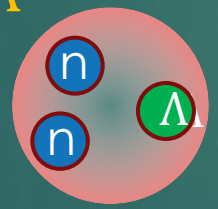
JLab E12-17-003



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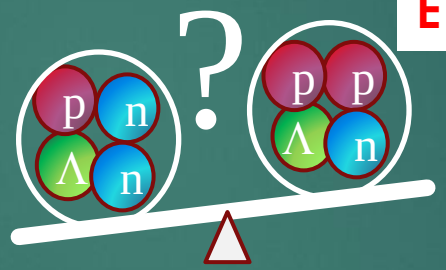
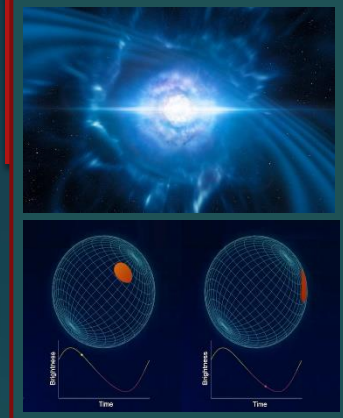


JLab E12-15-008 E12-20-013

Hyperon Puzzle

Why massive NS exists?



Recent astronomical observations

$A=$ ^{57}

10^{-1} m

S.A. Wood (JLab)	Hall A/C overview
S. Nagao (Tohoku Univ.)	PCS + Experimental setup
T. Gogami (Kyoto Univ.)	HKS (+HES) detector overview and status
D. Meekins (JLab) / T. Gogami (Kyoto Univ.)	Target design

Second Session 7th : Hall A/C current and future Preparation status of Experiment

Current problems of Λ hypernuclei

New method to study nuclear shape $^{27}_{\Lambda}\mathrm{Mg}$

Hypertriton Puzzle

MAMI

JLab E12-19-002

Shallow bound
Short lifetime

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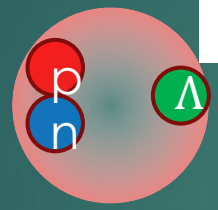
ELPH



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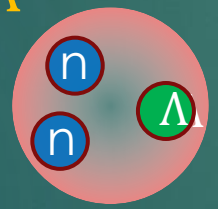
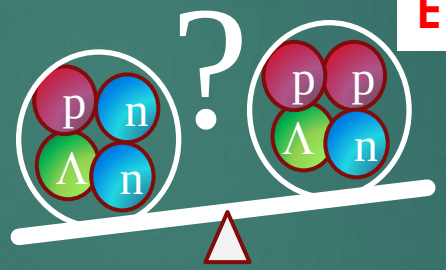


JLab E12-17-003

A=3

CSB of Λ Hypernuclei



JLab E12-15-008 E12-20-013

Hyperon Puzzle

Why massive NS exists?

Recent astronomical observations

$A \sim 10^{57}$

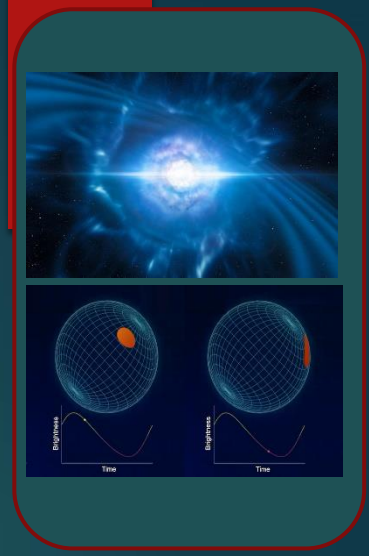
10^{4} m

K.N. Suzuki (Kyoto Univ.)	nnΛ analysis (1): cross section (arXiv:2110.09104 (nucl-ex))
B. Pandey (Hampton Univ.)	nnΛ analysis (2): peak search
K. Itabashi (Tohoku Univ.)	nnΛ analysis (3): Λ-n final state interaction

First Session 8th : nnΛ analysis

Current problems of Λ hypernuclei

New method to study nuclear shape $^{27}_{\Lambda}\mathrm{Mg}$



Recent astronomical observations

Hypertriton Puzzle

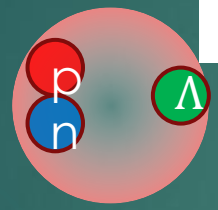
MAMI

JLab E12-19-002

Shallow bound
Short lifetime

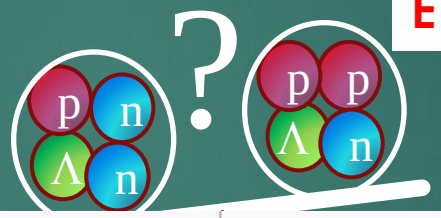
J-PARC

ELPH



CSB of Λ Hypernuclei

JLab E12-15-008 E12-20-013



Hyperon Puzzle

$^{3}_{\Lambda}n$ Puzzle

GSI

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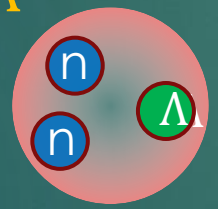
Not Exist?

JLab E12-17-003



A=3

10−15 m

sive

S. Nagao (Tohoku Univ.)	Brief introduction of the following talks
K. Okuyama (Tohoku Univ.)	Experimental performance study by Geant4 for the Hall C option
T. Akiyama (Tohoku Univ.)	Sieve slit study by Geant4 (PCS+HKS)
R. Kino (Tohoku Univ.)	Scintillation fiber detector for angle calibration
S. Nagano (Tohoku Univ.)	Status of new water Cherenkov detector

Second Session 8th : Hall-C option & New Detectors

Current problems of Λ hypernuclei

New method to study nuclear shape $^{27}_{\Lambda}\mathrm{Mg}$

Hypertriton Puzzle

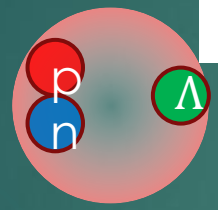
MAMI

JLab E12-19-002

Shallow bound
Short lifetime

J-PARC

ELPH



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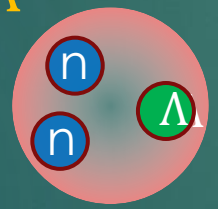

CSB of Λ Hypernuclei

Session 9th : Hall-C option

P. Brinza	Hall C drawings / modification / installation
T. Gogami (Kyoto Univ.)	Short summary for discussion

Hyperon Puzzle

JLab E12-15-008 E12-20-013

Why massive exists?

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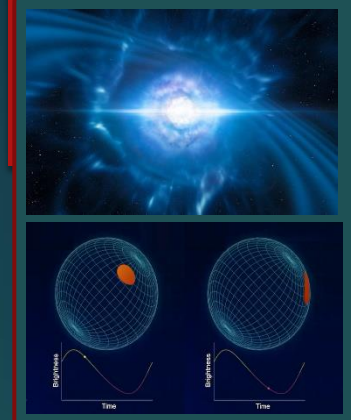
10^{-15} m

$A\sim 10^{57}$

10^{4} m

J-PARC HIHR



Recent astronomical observations

Jlab Hypernuclear Collaboration Meeting

07 Dec. 2021

Physics Overview of new experiment (A=40, 48) E12-15-008

SATOSHI N. NAKAMURA

TOHOKU UNIVERSITY

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)

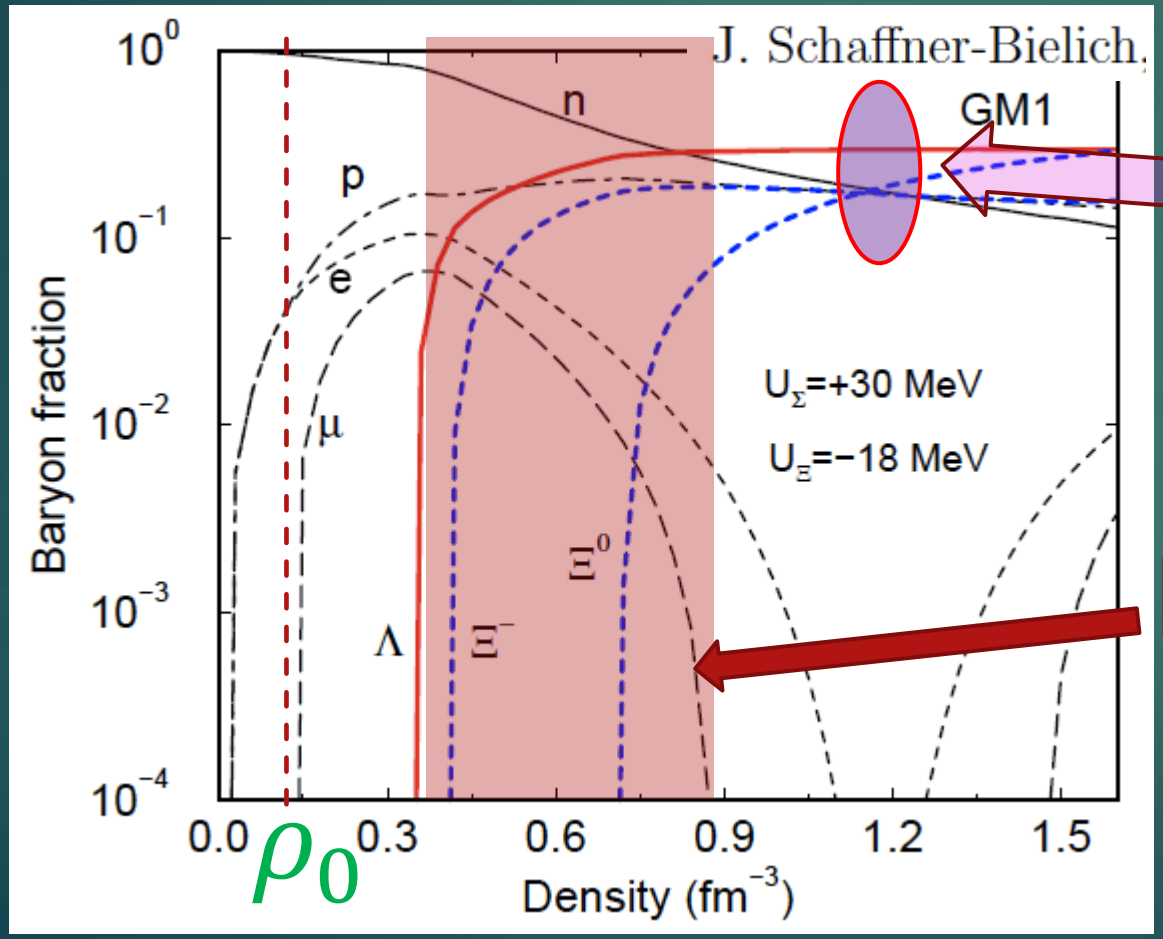
Based on discussions there :

Re-submitted C15-12-008 proposal to PAC44 and approved with grade-A.

Neutron star and strange hadronic matter

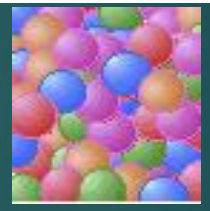
Sym. Nucl. Matter : Limit for size (due to Coulomb force)

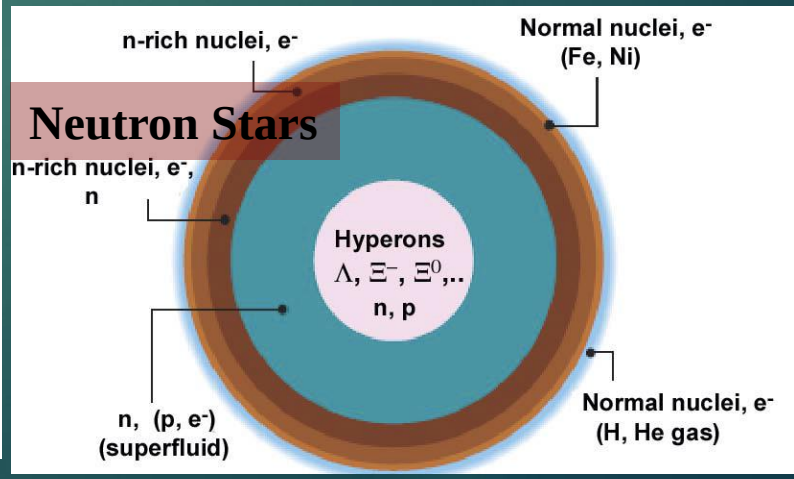
Asym. Nucl. Matter : Neutron Stars, Strange Hadronic Matter



Nu ~ Nd ~ Ns

p,n,Λ,Ξ^0,Ξ^-

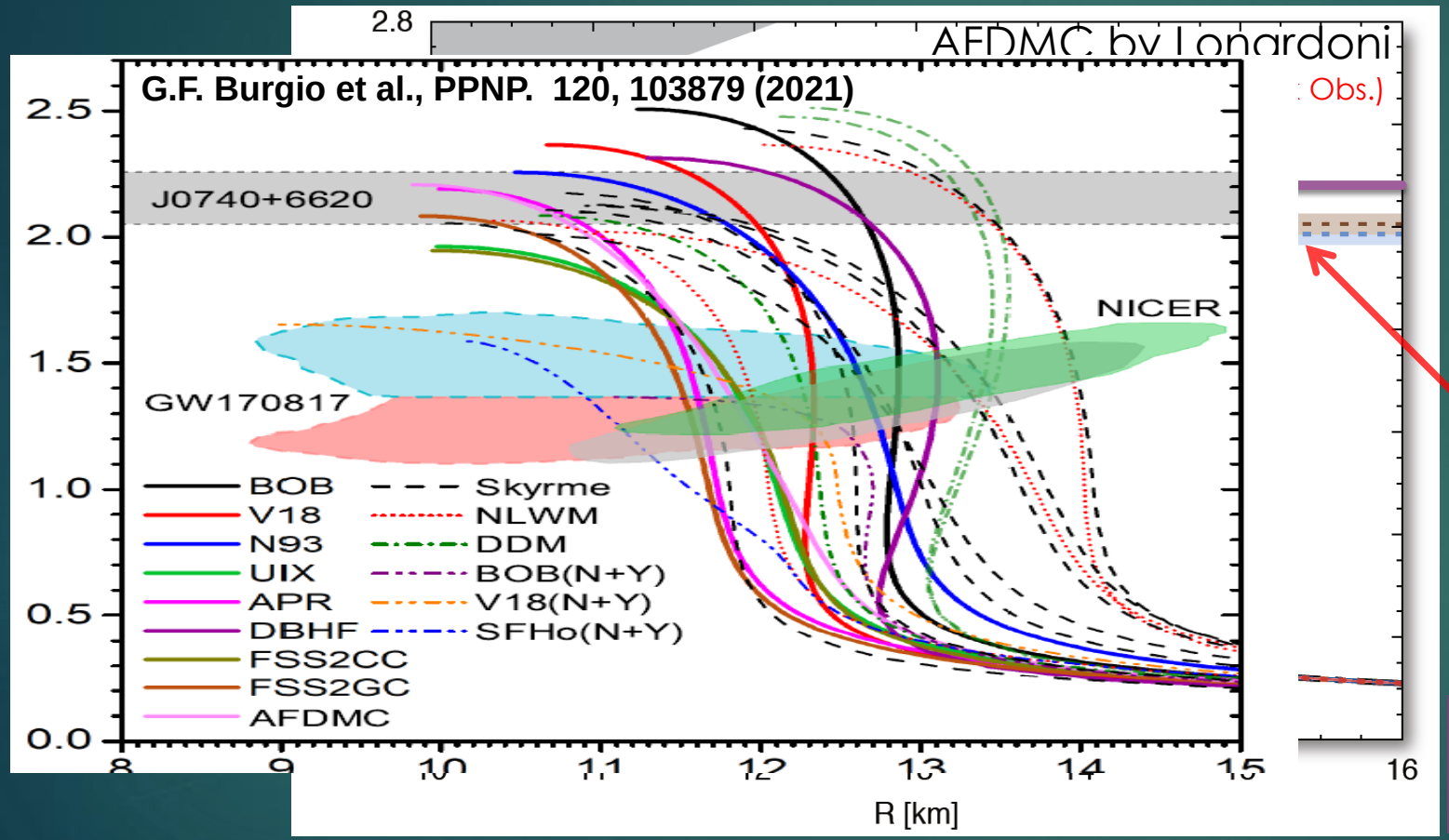




Hyperon Puzzle

Based on our knowledge on Baryonic Force:

Hyperon naturally appear at high density ($\rho=2\sim3\rho_0$)



Too Soft EOS

Contradict to observation

2 $M_\odot$ Neutron Stars

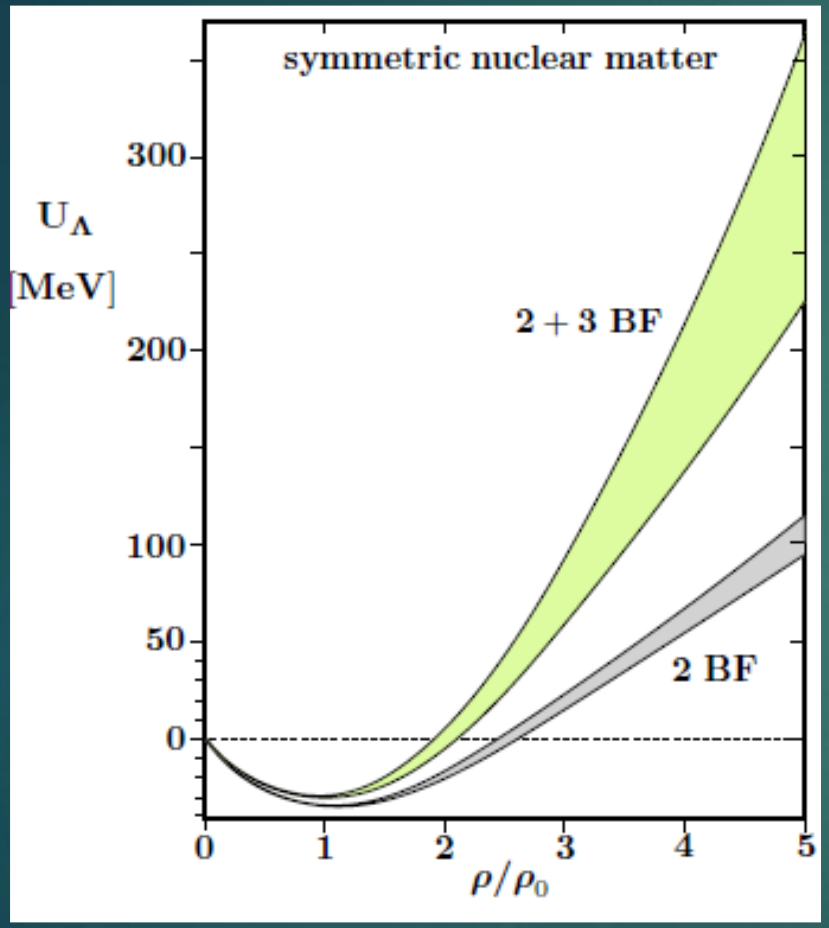
Additional Force to make EOS stiff

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.

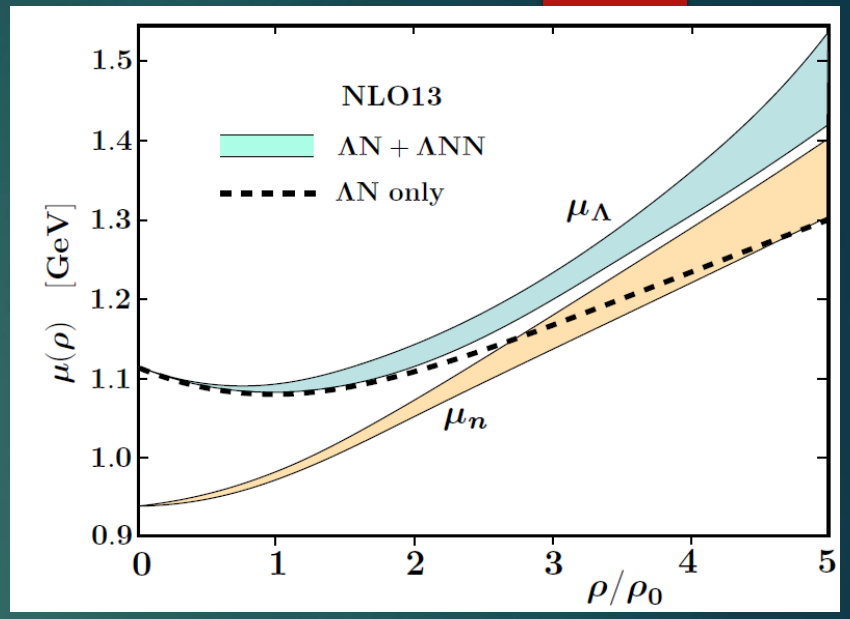
Variational Meth. + AV18+UIX by Togashi et al., PRC 93 (2016) 035808

3BF recovers stiffness



With 3BRF
recover stiffness

With Hyperon
too Soft



ChEFT(NLO: Saturation Decuplet)

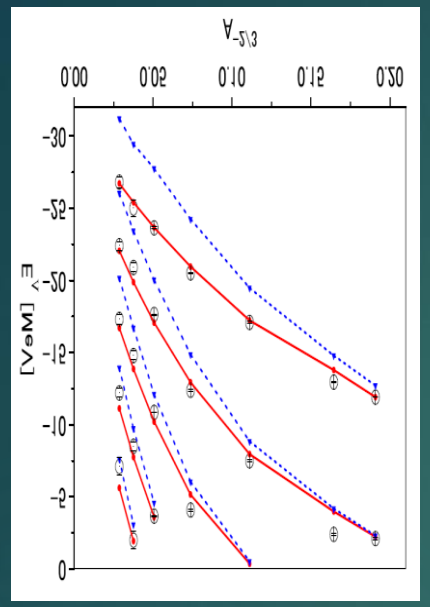
3BF → Density Dep. Effective 2BF

Brueckner-Bethe-Goldstone eq.

ΛN-ΣN,ΛNN-ΣNN coupled channels

D.Gerstung et al., Eur. Phys. J. A (2020) 56:175.

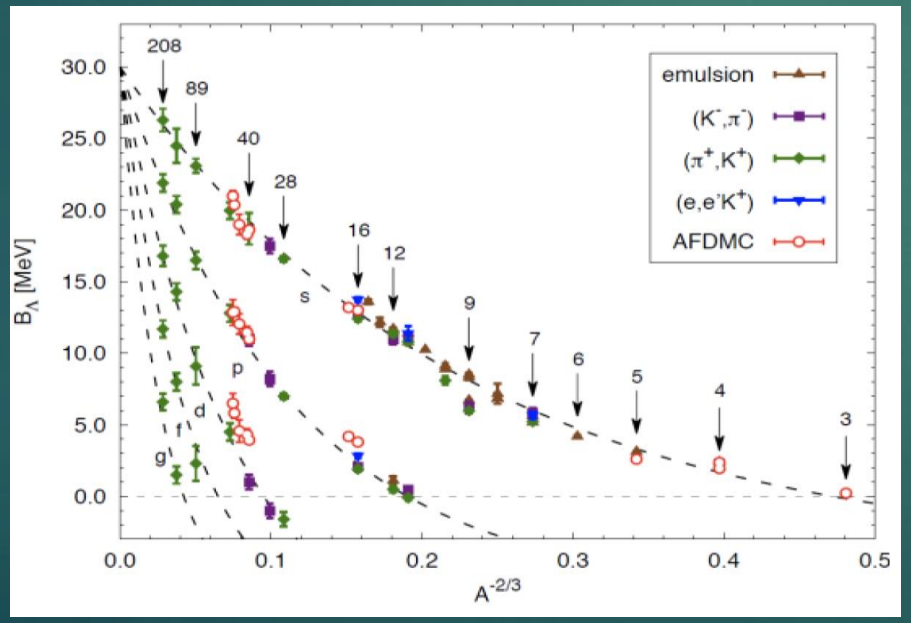
Λ Single Particle Energies of Λ Hypernuclei by Various Calculations



M.M. Nagels et al., PRC 99 (2019) 044003.

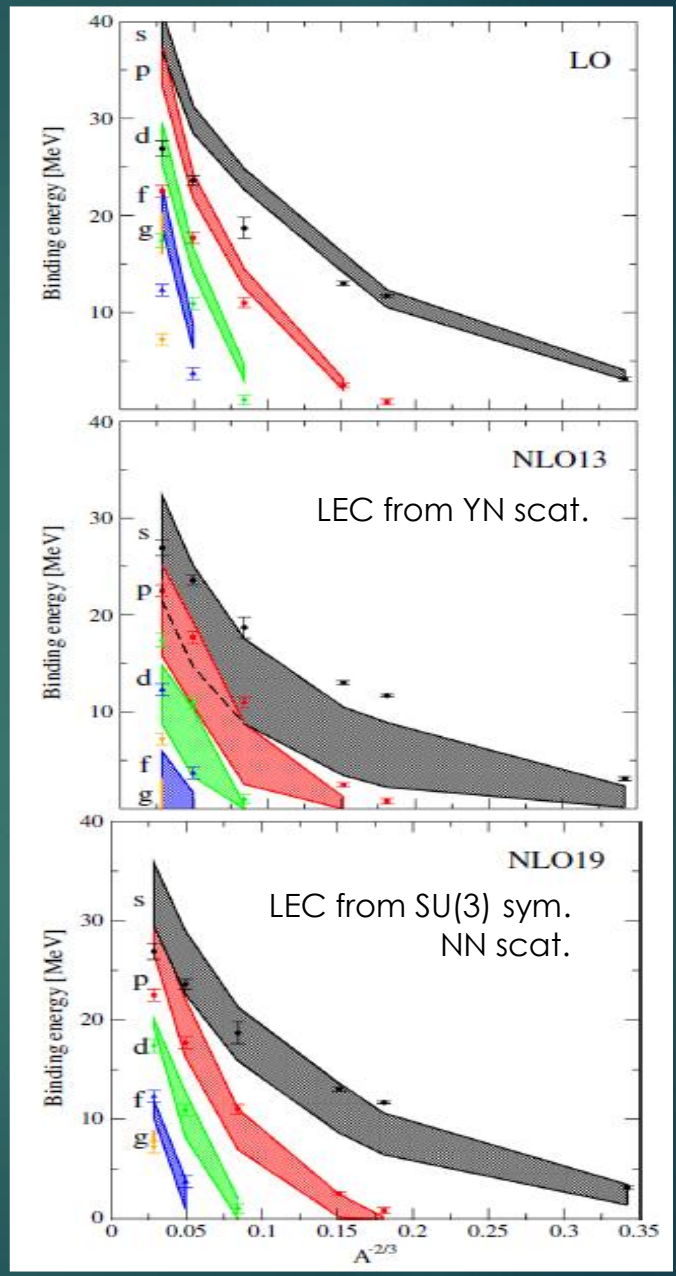
ESC16
ESC16+ (Inc. 3BF)
G-matrix

AFDMC



D.Lonardoni and F. Pederiva, arXiv:1711.07521.

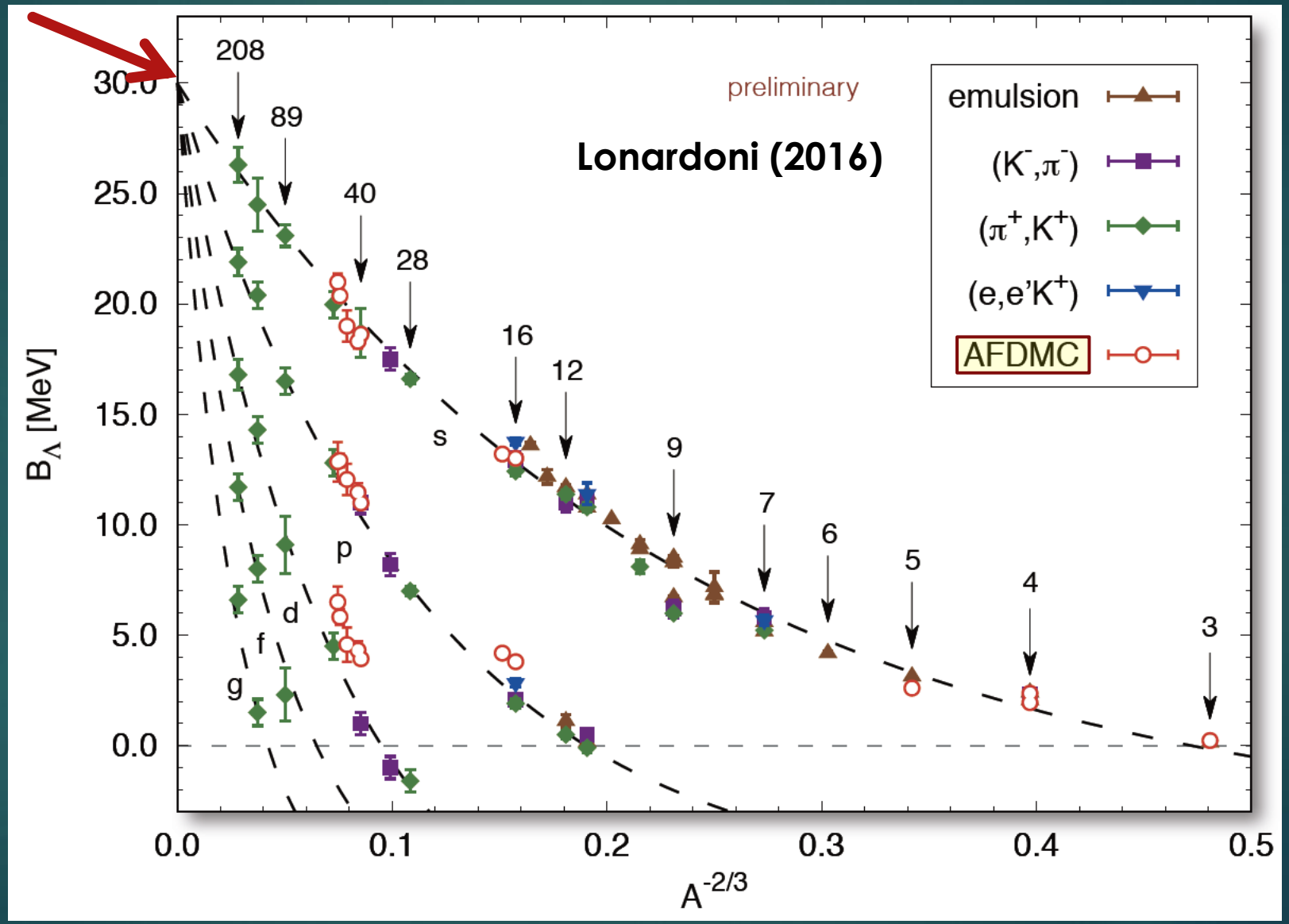
ChEFT



J.Haidenbauer, I.Vidana, EPJA (2020) 56:55.

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

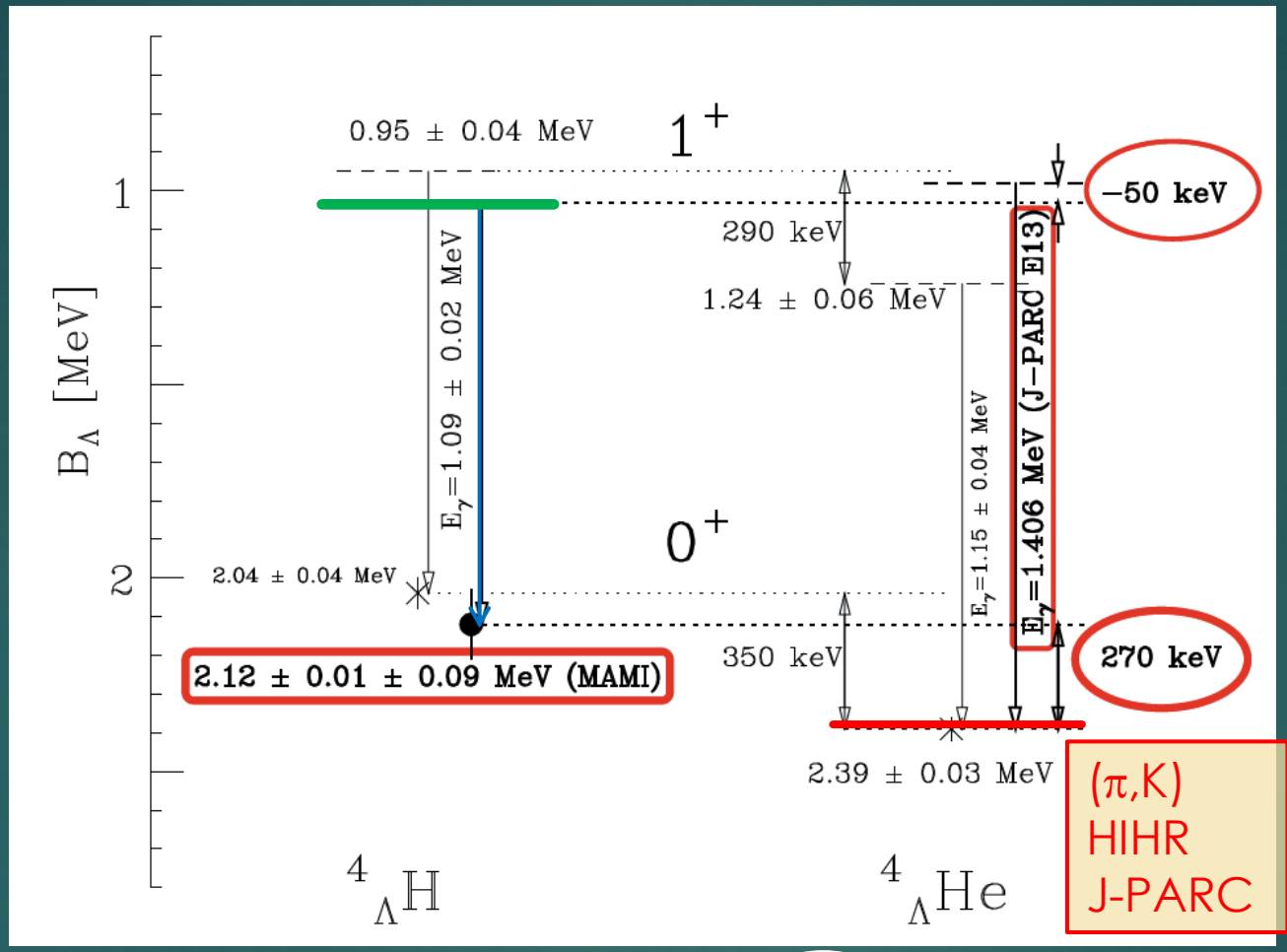
$^{4}_{\Lambda}$H g.s. measurement by decay π spectroscopy

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

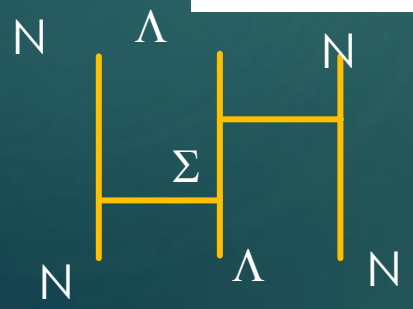
ΛN interaction has large **isospin dependence**.

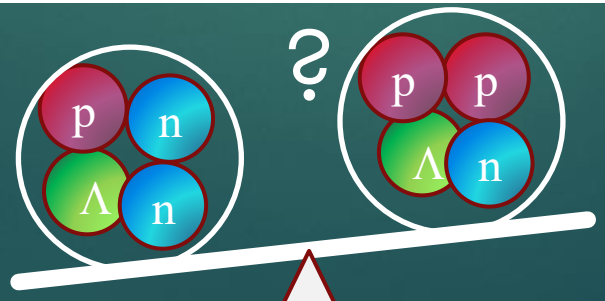


Small CSB

Large CSB

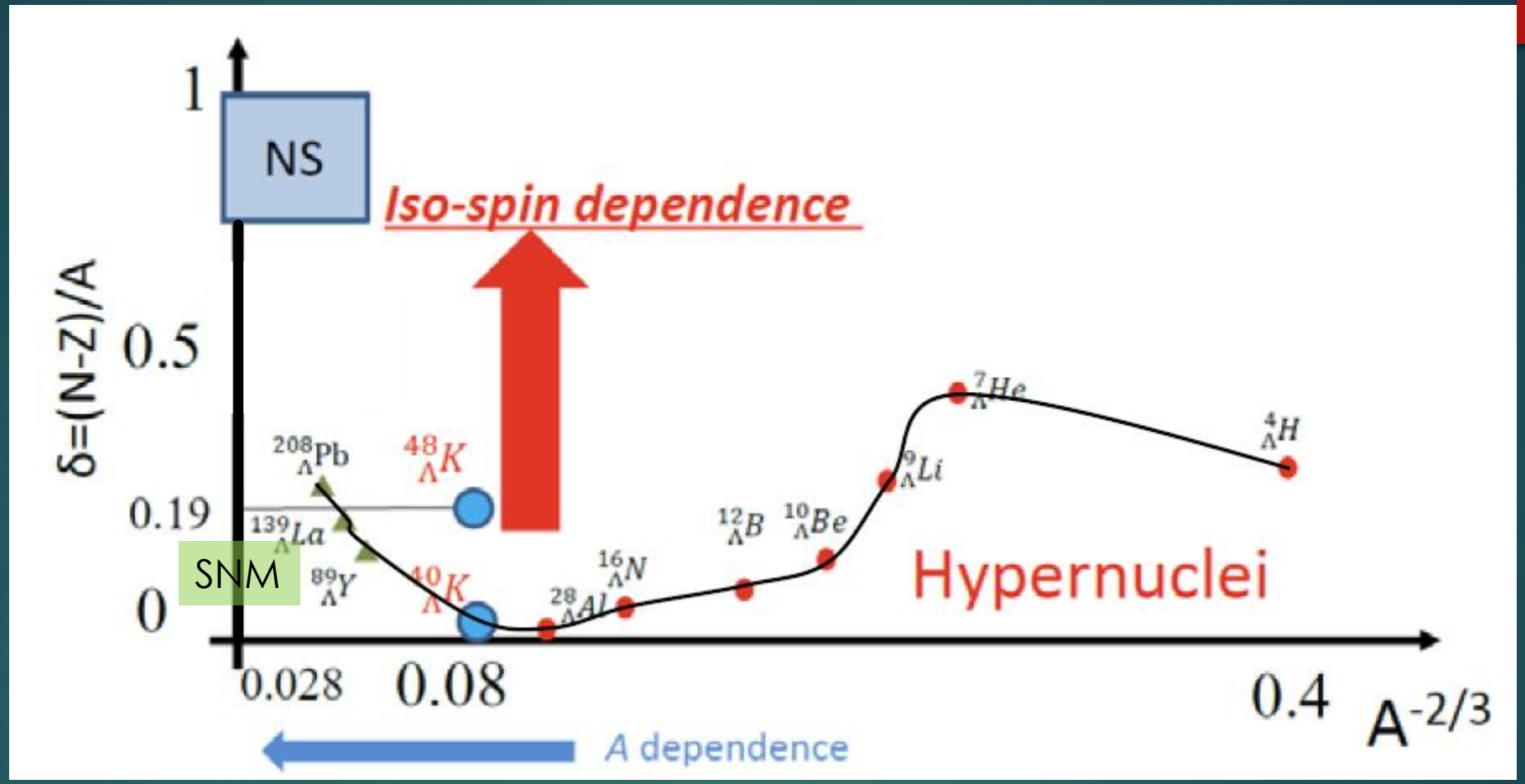
(π,K)
HIHR
J-PARC





ΛN-ΣN coupling is a key

NS EOS with hyperon and 3BRF

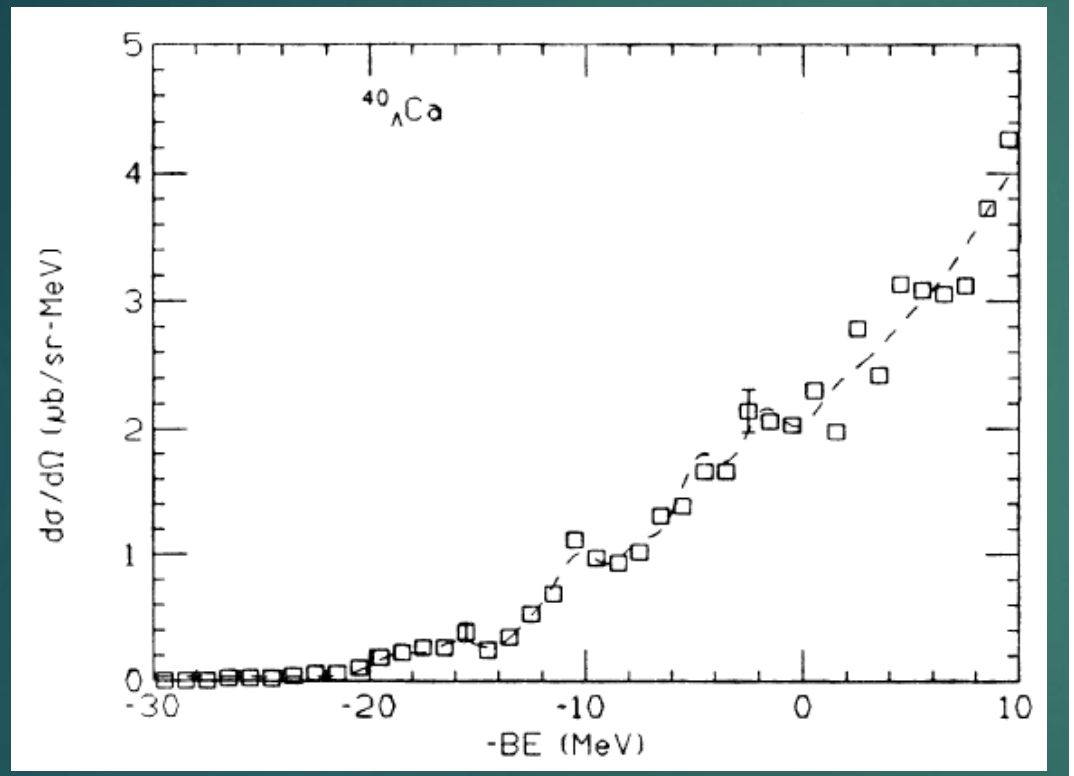


Key issues : A Dependence of 3BRF

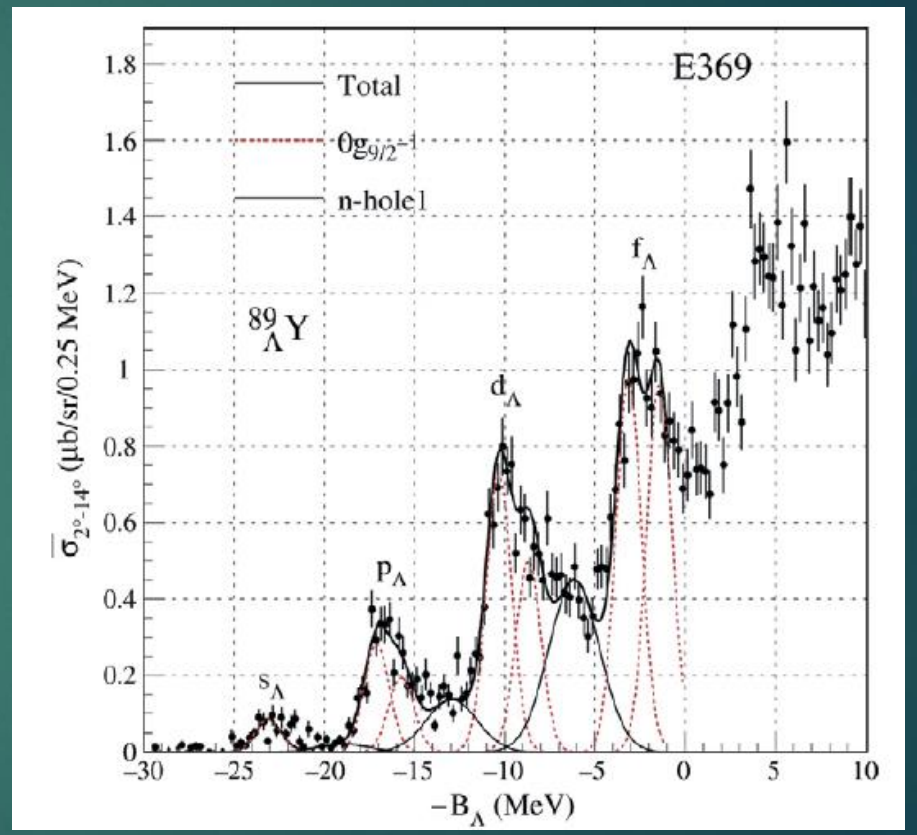
Isospin Dependence

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

Mid-heavy data from (π,K) exp.

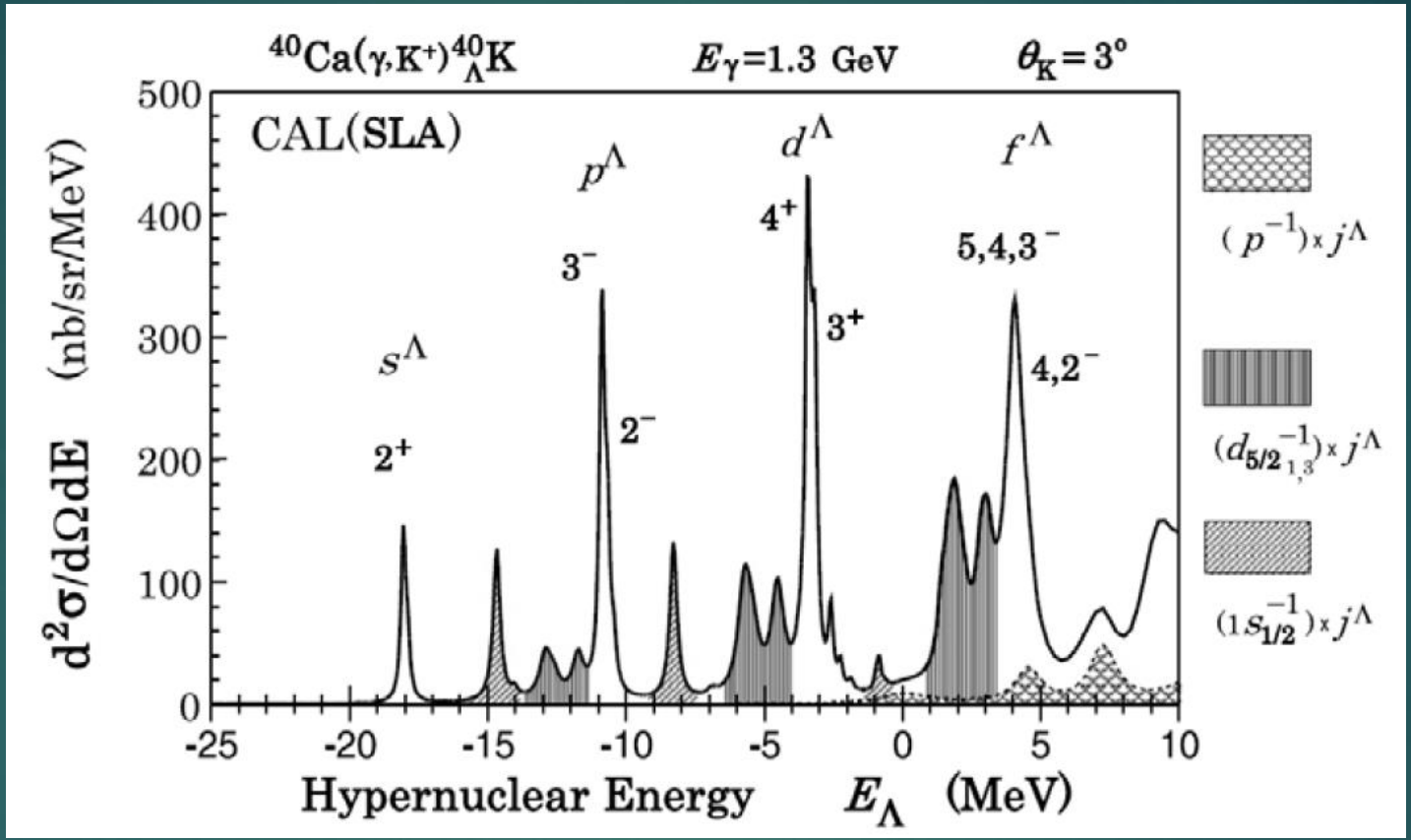


P.H.Pile et al. PRL 20 (1991) 2585.



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

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



0.3 MeV (FHWM) resolution assumed.

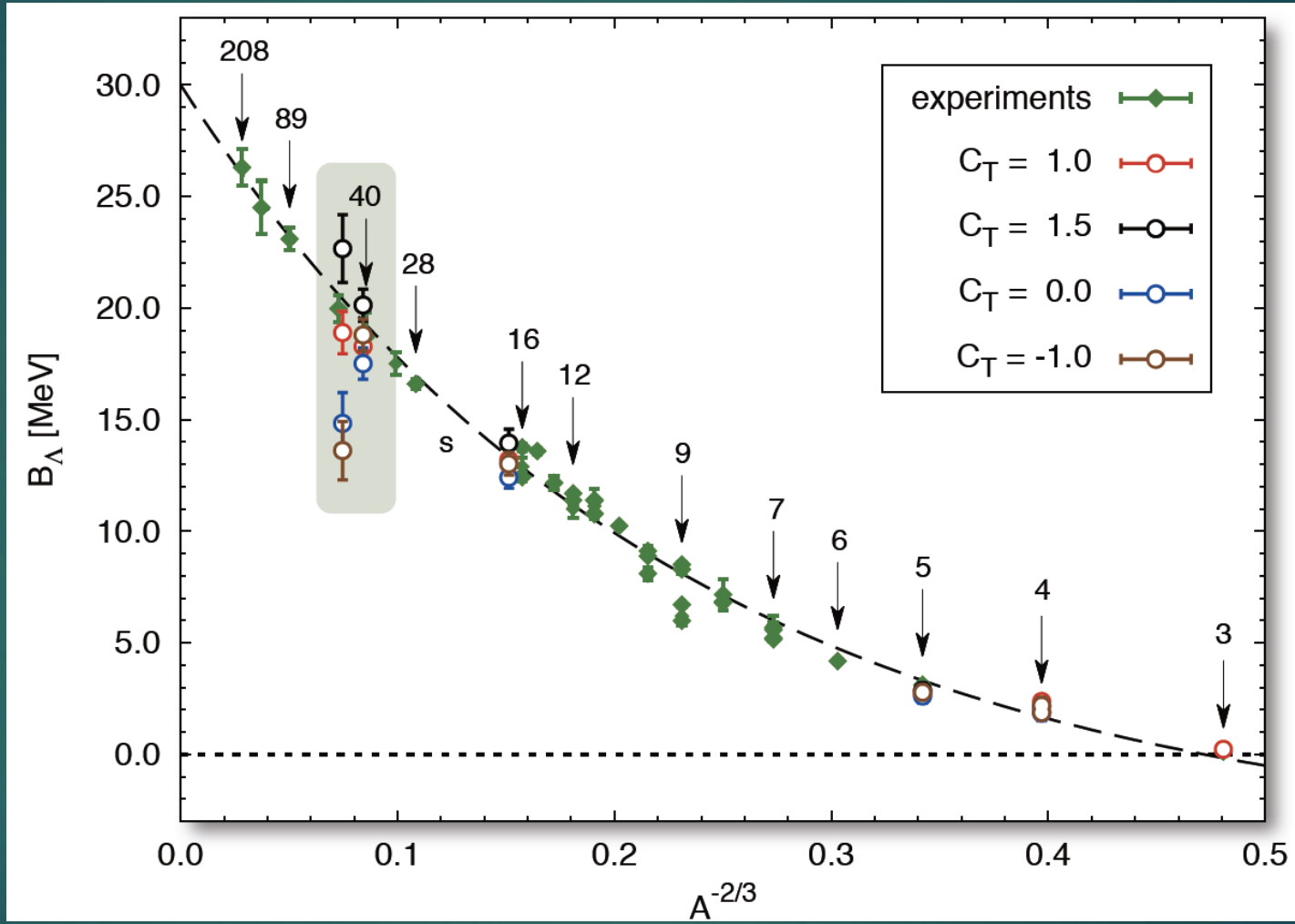
P. Bydzovski et al. NPA881 (2012) 199.

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

Reliable absolute energy calibration.
Excellent energy resolution.

<100 keV accuracy
Determination of B_Λ

ΛNN/ΛNP dependence of B_Λ



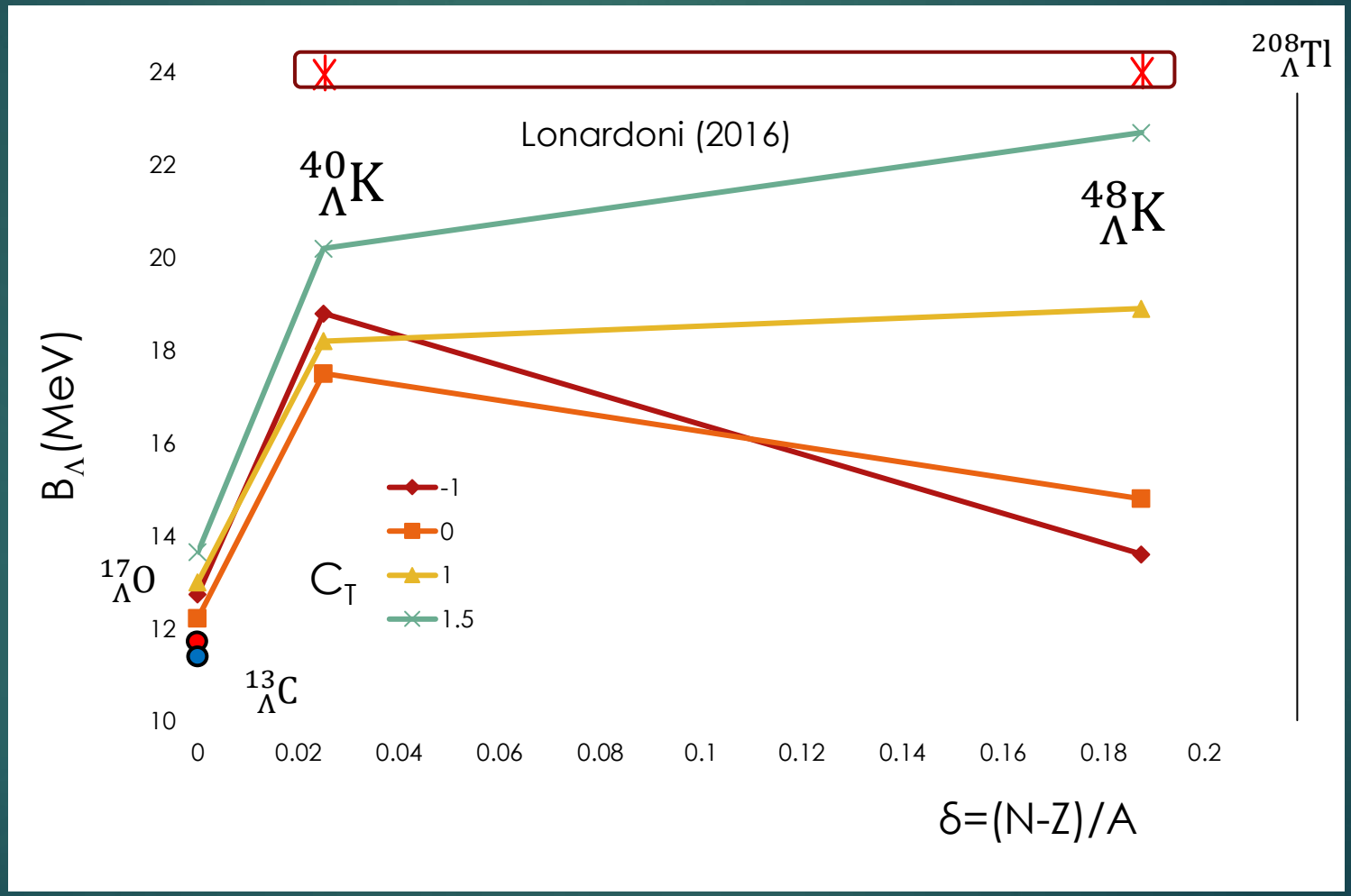
Introduced ΛNN potential

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

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

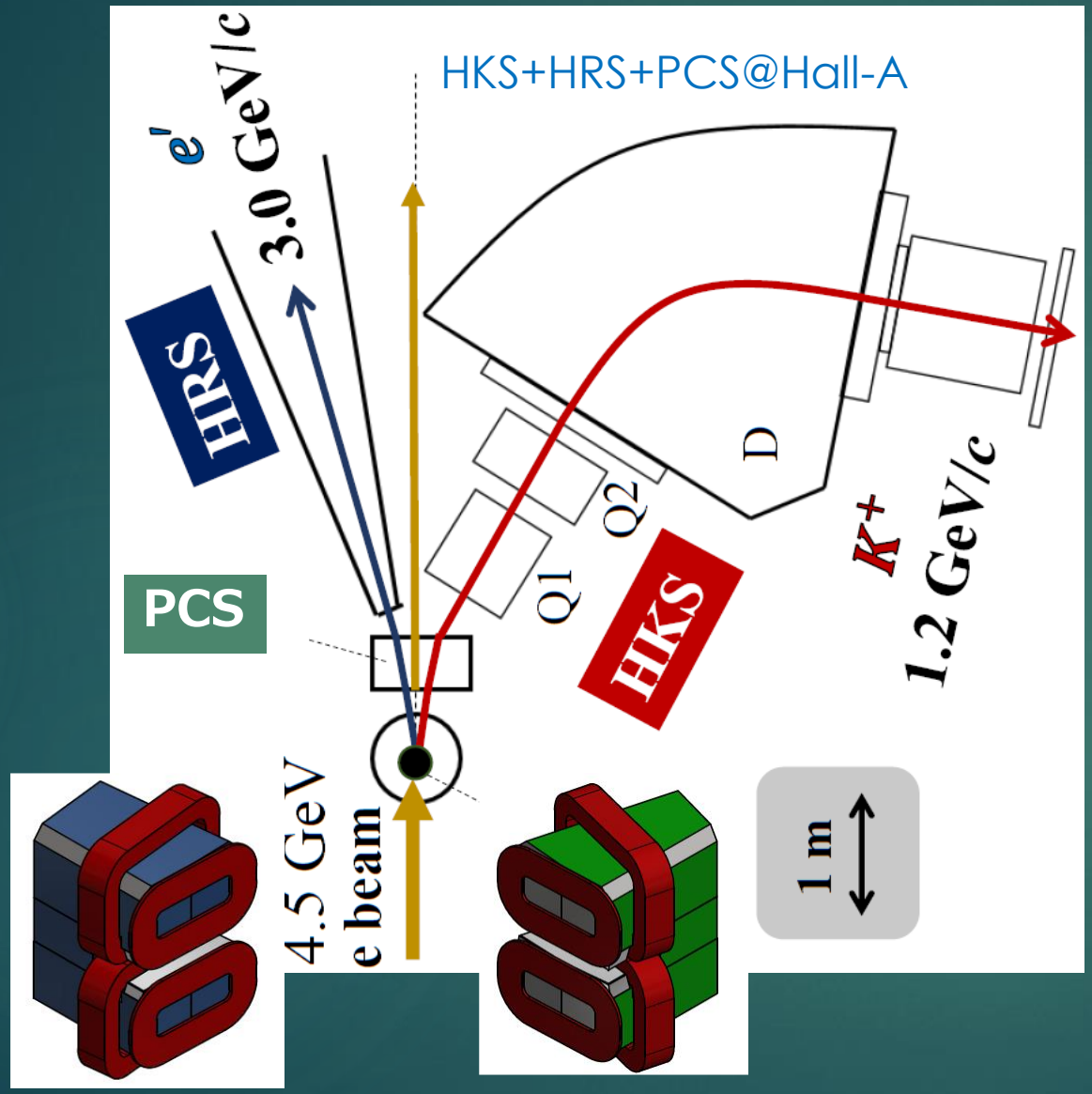


Isotopically enriched targets

110 mg, Φ1.27cm, 0.5mm thick (79 mg/cm^2)
^{40}Ca (99.96%) and ^{48}Ca (95.99%) targets at JLab.

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

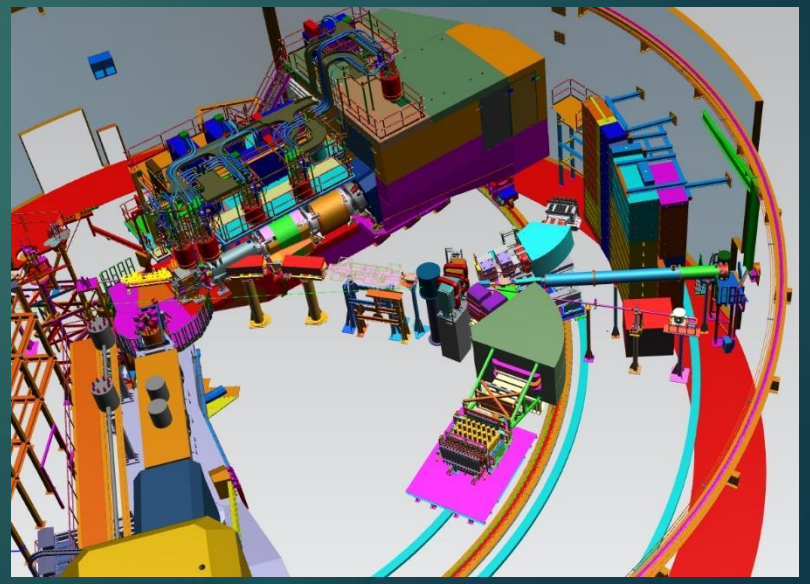
HKS + HES + PCS in Hall-A



2020/3/13 @ TOKIN (SENDAI)

New Pair Charge Sep. Mag.

HKS+HES+PCS@Hall-C



Requested Beamtime

	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 $\Lambda\mathrm{NN}$ 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, $\Lambda\mathrm{NN}$ 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 (28 PAC days including calibrations).

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