ELPH 研究会 C031
「多彩なビーム実験と
多様な理論的手法で迫る
ハドロン間相互作用」

Satoshi N. Nakamura

Tohoku University

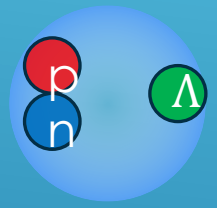
JLabにおける Λハイパー核分光研究の 現在、未来

4th Nov. 2021

CURRENT PROBLEMS ON Λ HYPERNUCLEI

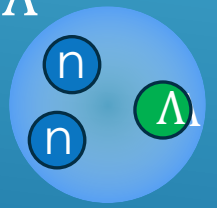
Hypertriton Puzzle

Shallow bound
Short lifetime

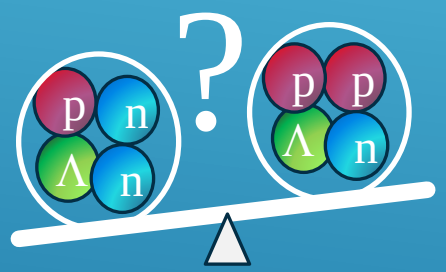


Bound?
Resonance?
Not Exist?

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



CSB of Λ Hypernuclei



Hyperon Puzzle

Why massive
NS exists?

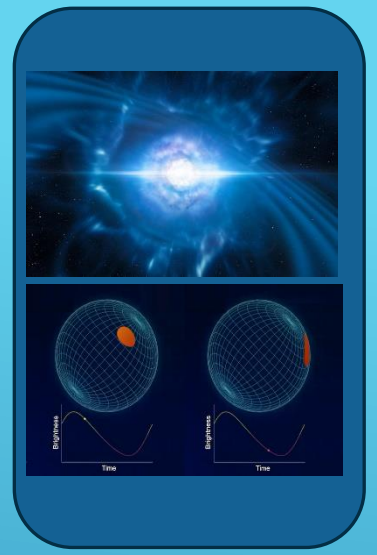
A=3

10^{-15} m

$A \sim 10^{57}$

10^{4} m

CURRENT PROBLEMS ON Λ HYPERNUCLEI



Recent astronomical observations

Hypertriton Puzzle

MAMI

JLab E12-19-002

Shallow bound
Short lifetime

J-PARC

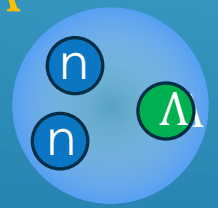
ELPH

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

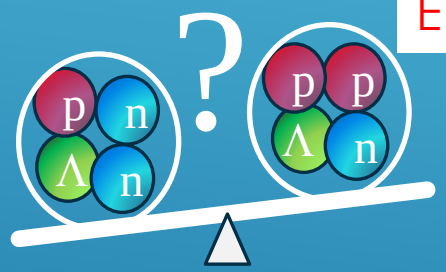
GSI

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?

$A=3$

10^{-15} m

$A\sim10^{57}$

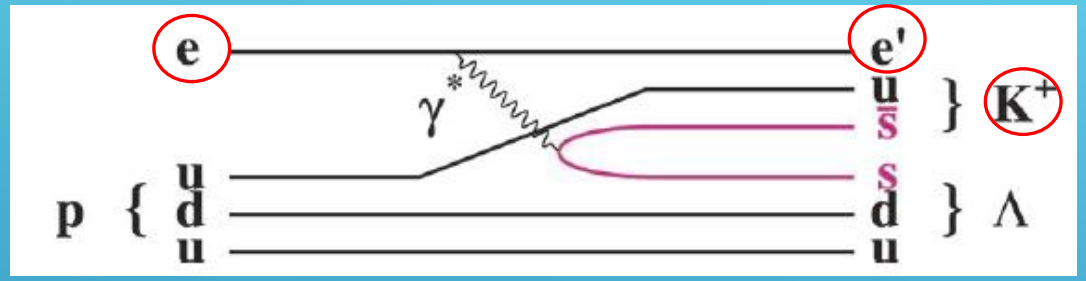
10^{4} m

J-PARC HIHR

$^{9}_{\Lambda}$Li T.Gogami et al. PRC 103 (2021) L041301.

Electron beam vs. meson beams

JLab, MAMI



(e,e'K$^+$)

Excellent mass resolution

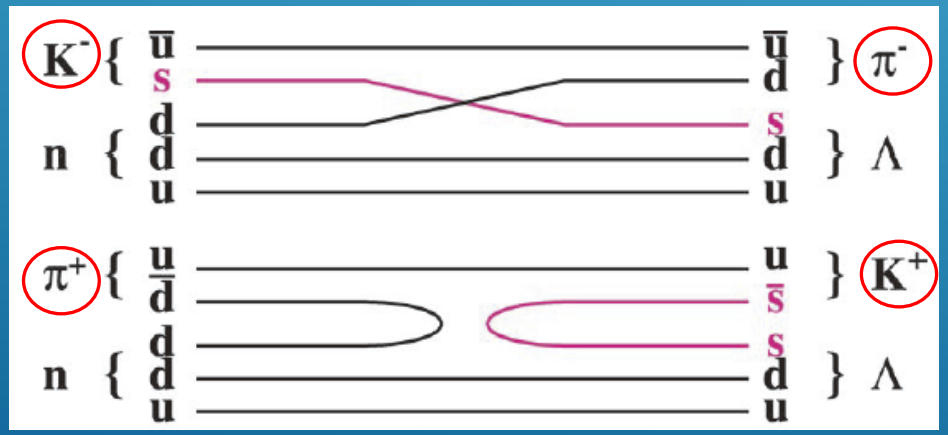
~ 0.5 MeV(FWHM)

Absolute energy calibration

p(e,e'K$^+$) Λ, Σ^0

Thin target (isotopically enriched)

eg. ^{40,48}Ca, ^{3}H



(K$^-$, π$^-$)

1-2 MeV resolution

Normalized to $^{12}_{\Lambda}$C mass

(π$^+$, K$^+$)

HIHR

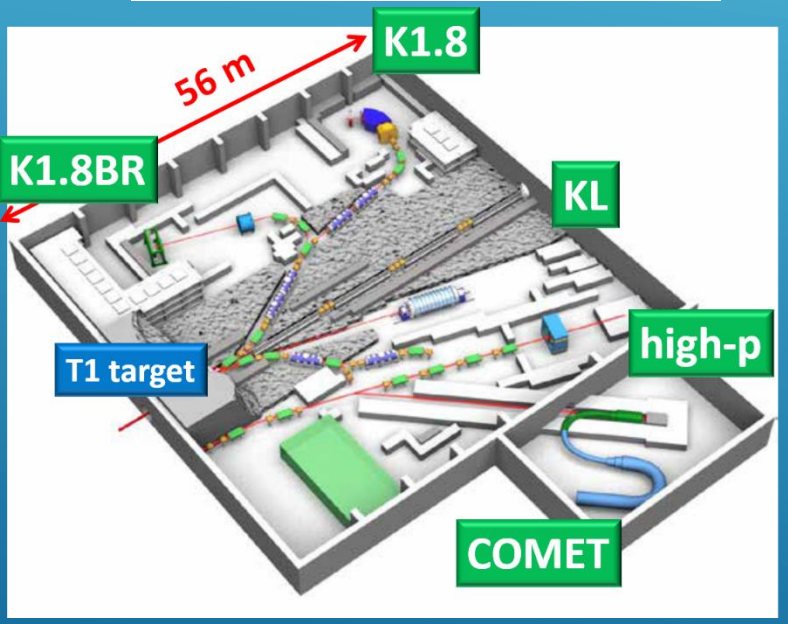
Excellent mass resolution

< 0.4 MeV

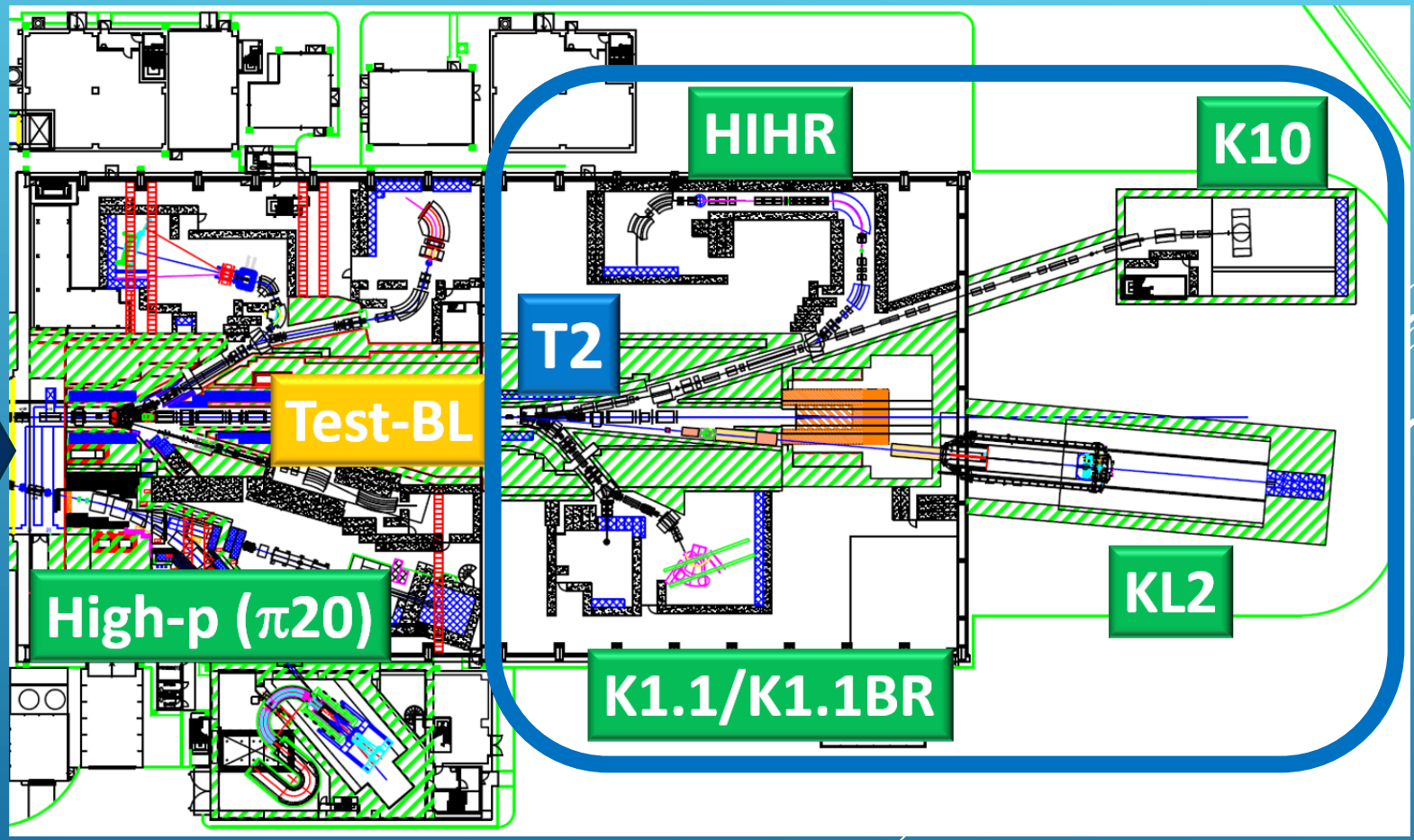
Thin target (isotopically enriched)

Hadron Experimental Facility EXtension (HEF-EX) PROJECT @J-PARC

Present facility

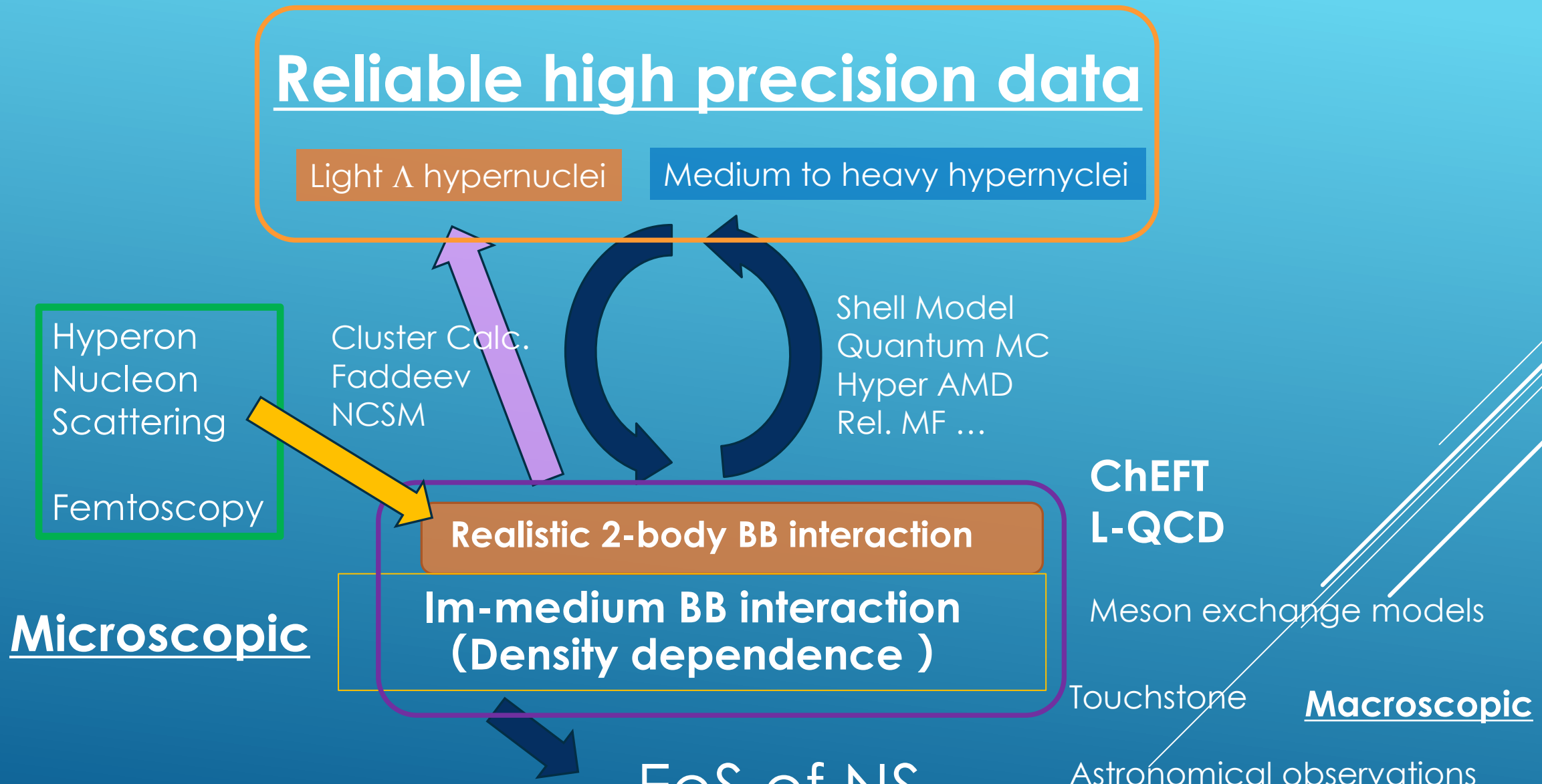


1 production target (T1) +
2 charged beamlines (K1.8/1.8BR, High-p)
1 neutral beamline (KL)
1 muon beamline (COMET)

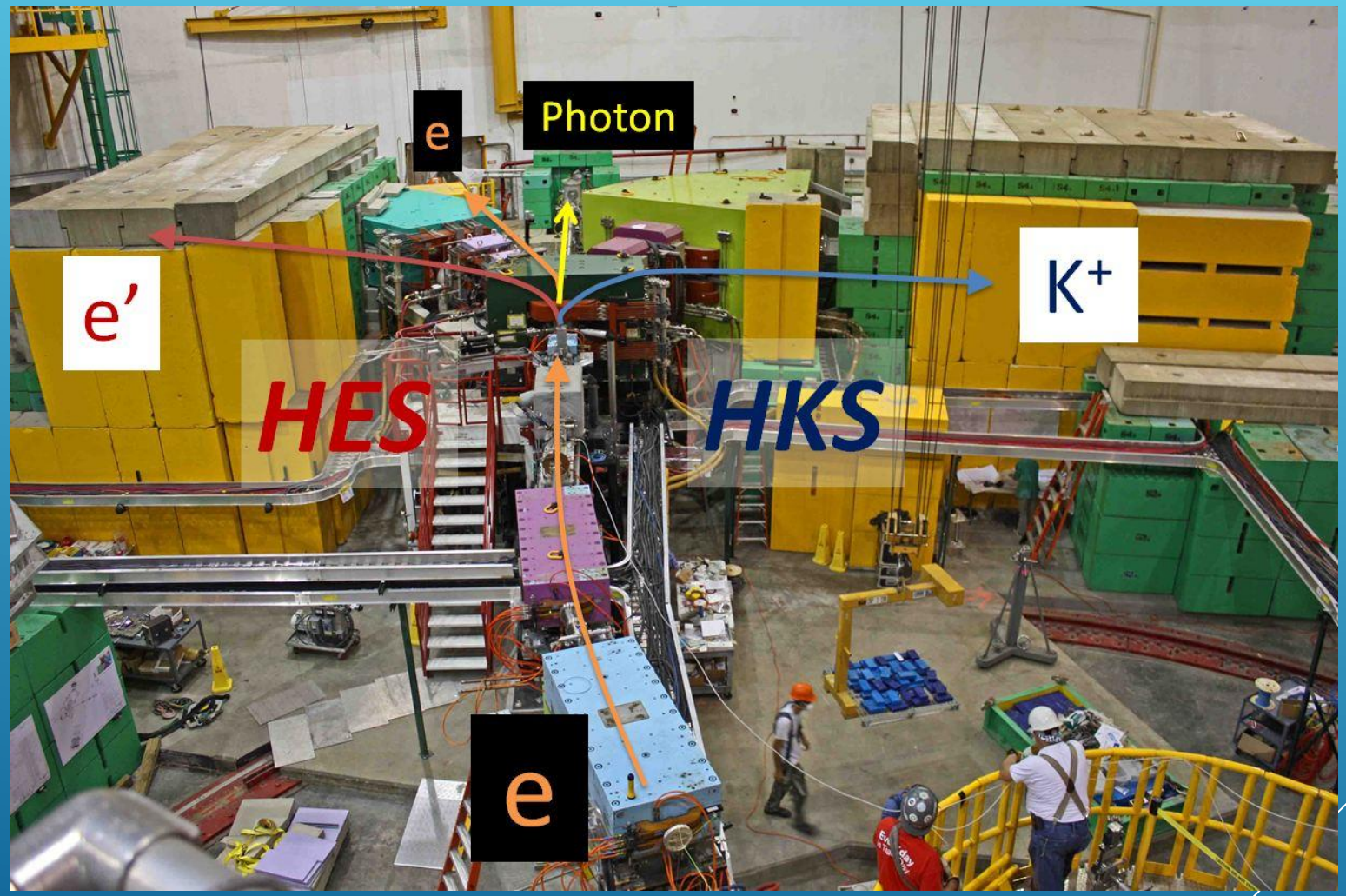


1 new production target (T2) +
4 new beamlines (HIHR, K1.1/K1.1BR, KL2, K10) +
2 modified beamlines (High-p (π20), Test-BL)

Strategy to solve the hyperon puzzle

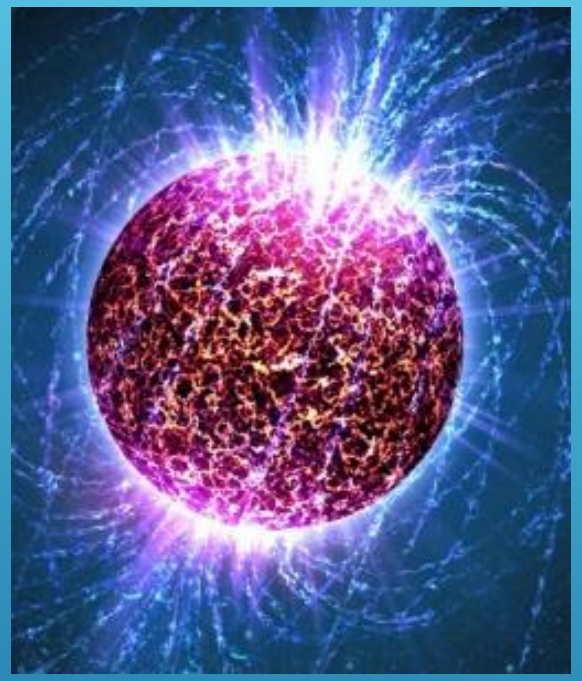


(e,e'K^+) reaction spectroscopy



JLab Hall-C 2009

HYPERON PUZZLE



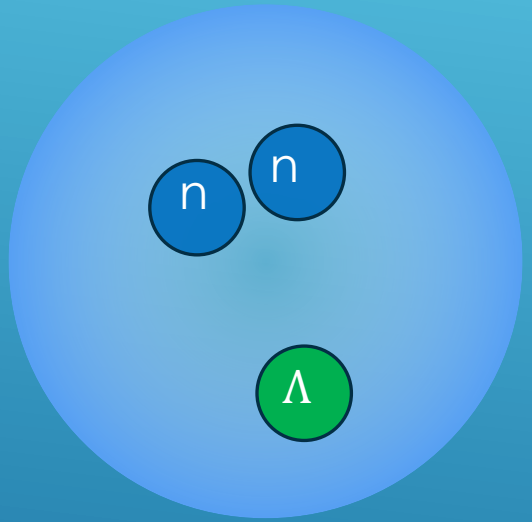
Two solar mass neutron stars

E12-15-008: ^{40,48}Ca targets

E12-19-002 Light targets

E12-18-013 ^{208}Pb targets

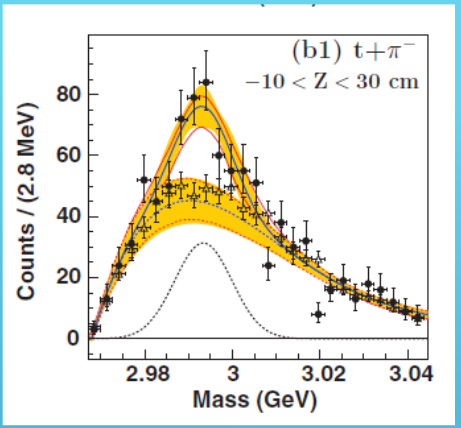
${}^{3}_{\Lambda}n$ Puzzle



E12-17-003 ^{3}H target

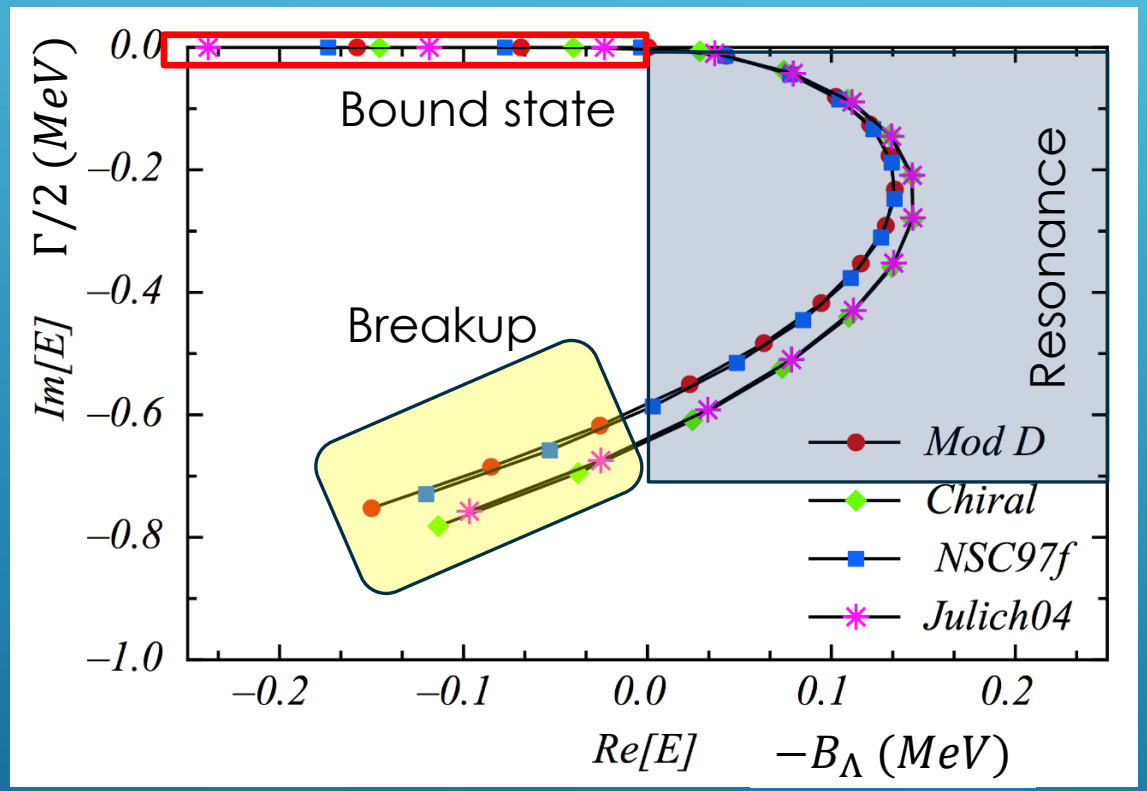
JLab E12-17-003
Λn interaction study by investigation of Λnn resonance

Jlab PAC45 approved as "High-Impact" exp.

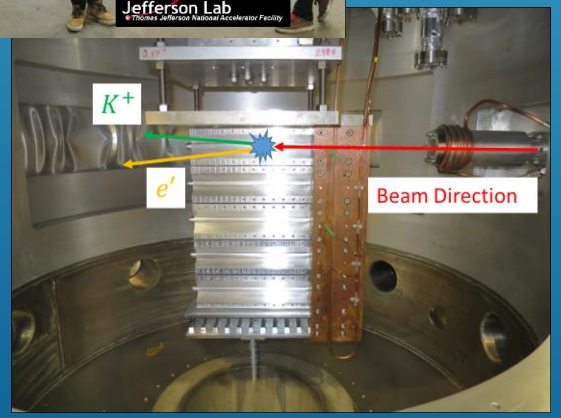


C.Rappold et al.
PRC 88041001(R) (2013)

$^{3}H(e, e'K^{+})nn\Lambda$



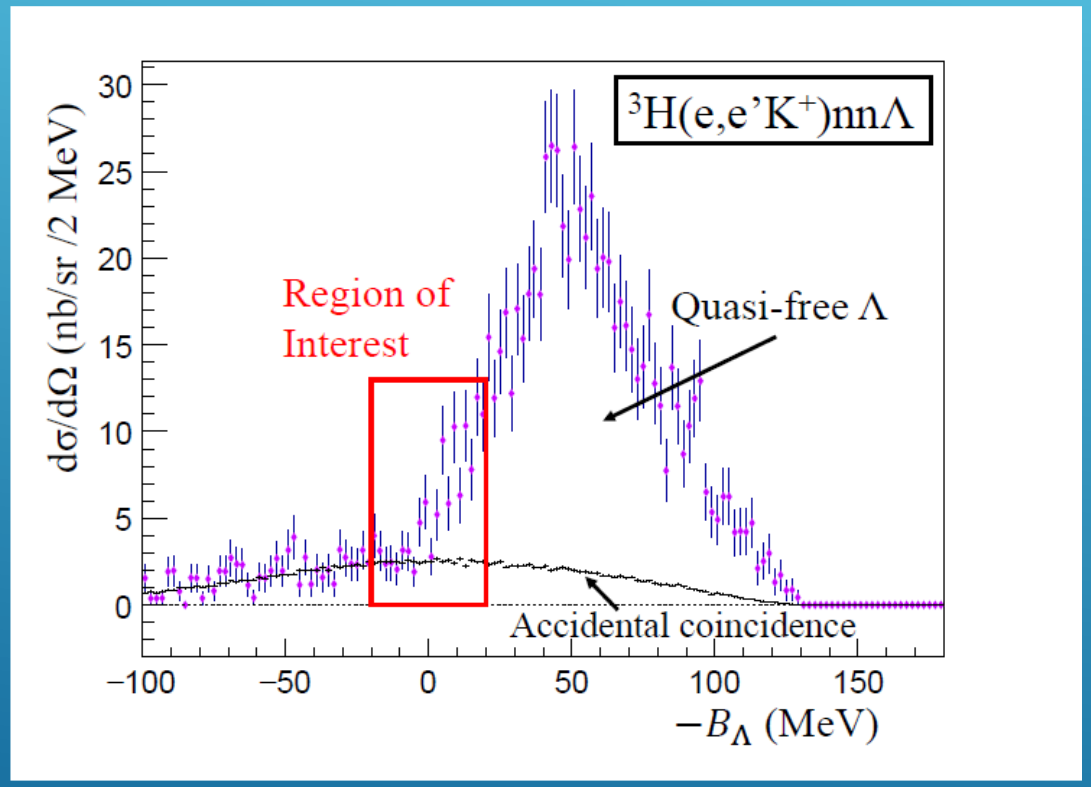
I.R.Afnan and B.F.Gibson, PRC 92, 054608 (2015)



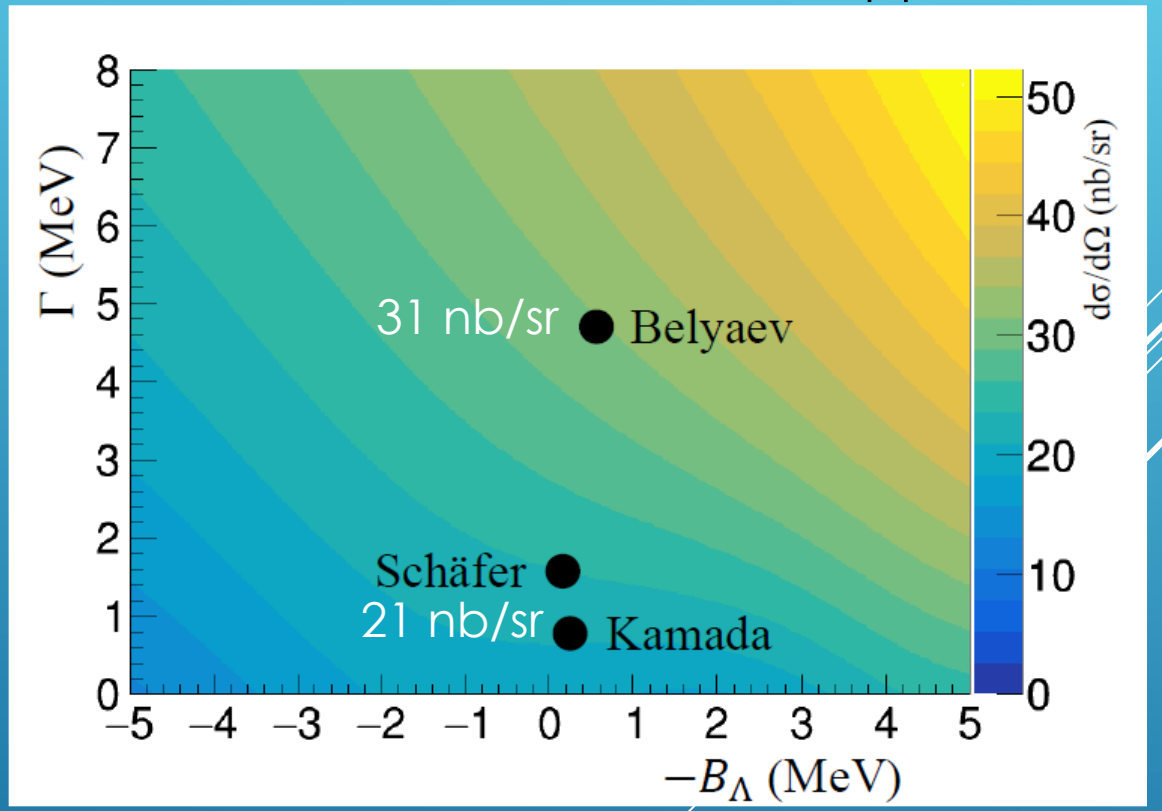
Target	Thickness [mg/cm^2]	Number of incident electrons
^{3}H	84.8	1.0×10^{20}
^{1}H	70.8	3.0×10^{19}

JLab E12-17-003

Λn interaction study by investigation of Λnn resonance



90% CL upperlimit



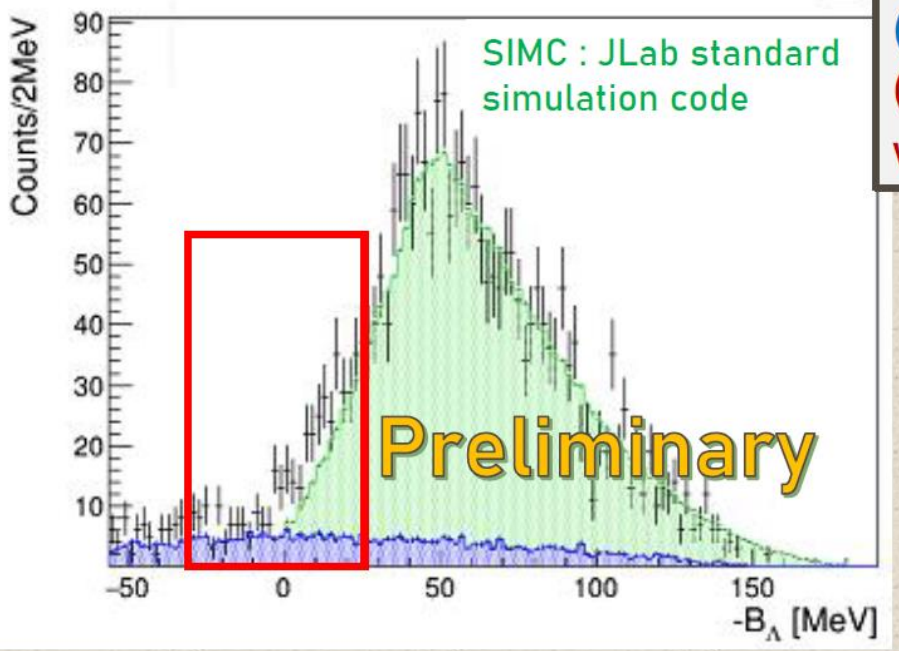
K.N.Suzuki et al. arXiv:2110.09104 (submitted to PTEP)

PRELIMINARY RESULT

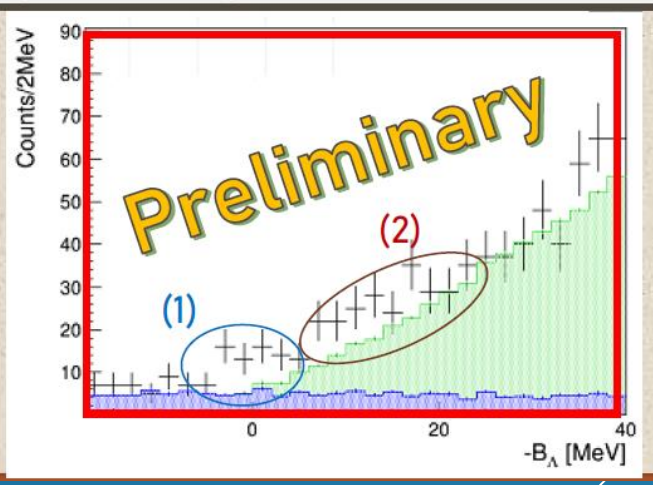
Difference between data and simulation

QF−Λ distribution with JLab standard simulation code (SIMC)

Physics : fermi momentum, spectral function, kaon decay, radiative correlations



(1) some events around threshold exist.
(2) there are excess events($0 < -B_\Lambda < 20$ MeV) which are not explained by SIMC.



Possible FSI effects

From K.Itabashi, APFB2020

HYPERON PUZZLE

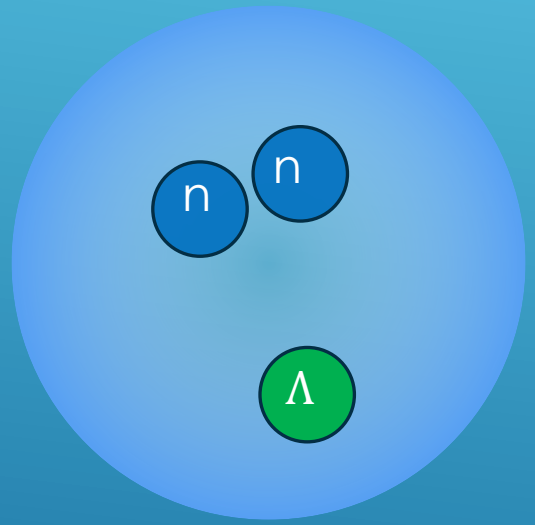
Two solar mass neutron stars

E12-15-008 ^{40,48}Ca targets

E12-19-002 Light targets

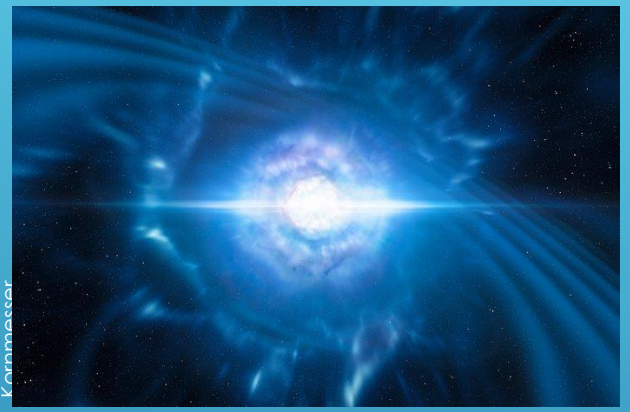
E12-18-013 ^{208}Pb targets

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



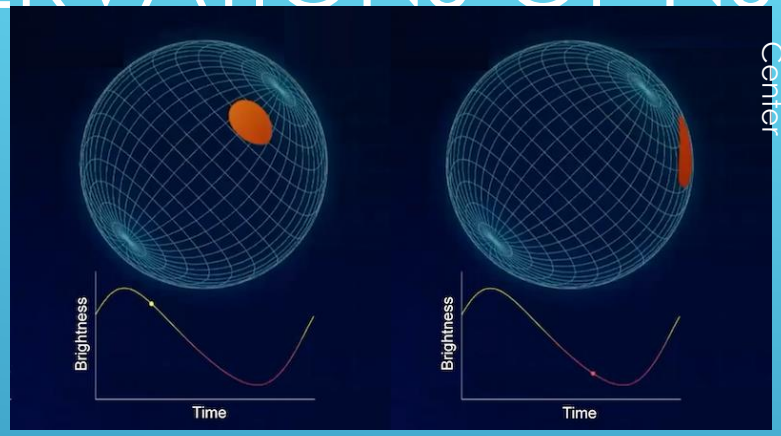
E12-17-003 ^{3}H target

NEW ASTRONOMICAL OBSERVATIONS OF NS



CC4.0 ESO/L. Calçada/M. Kornmesser

Gravitation Wave from neutron star mergers
LIGO/Virgo PRL **119**, 161101 (2017)

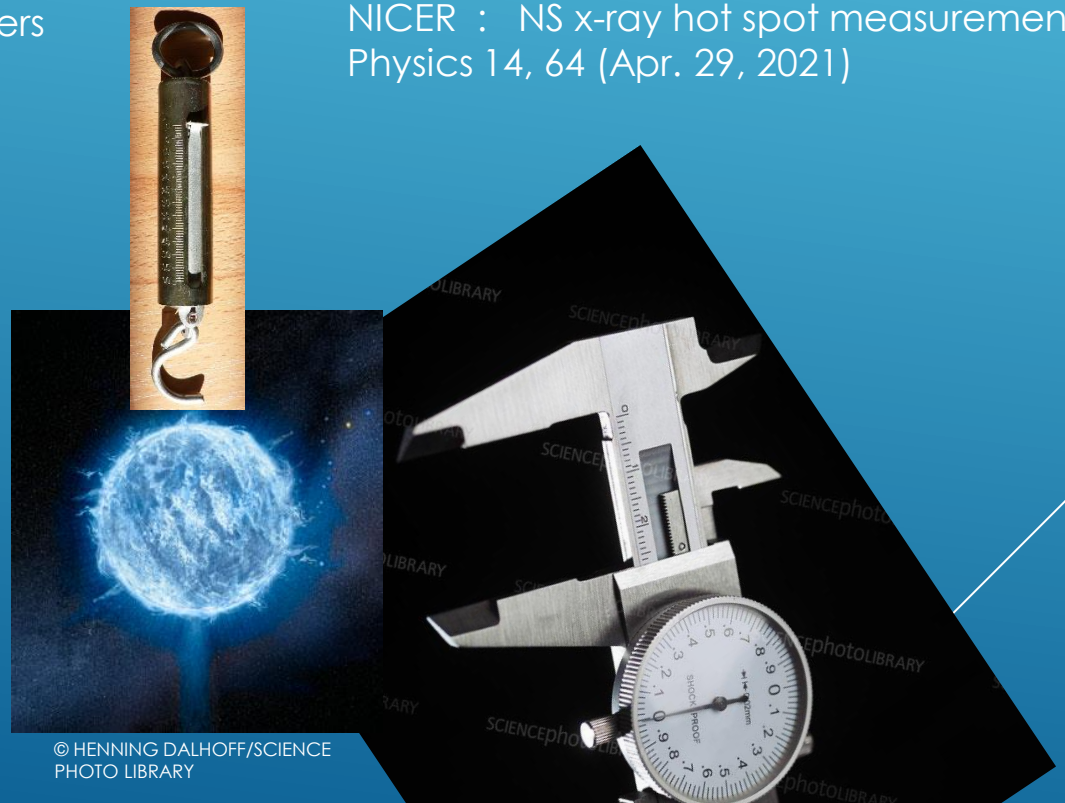


Goddard Space Flight Center

NICER ： NS x-ray hot spot measurement
Physics 14, 64 (Apr. 29, 2021)

Great progresses
Macroscopic features of NS

Microscopic understanding
becomes more important!



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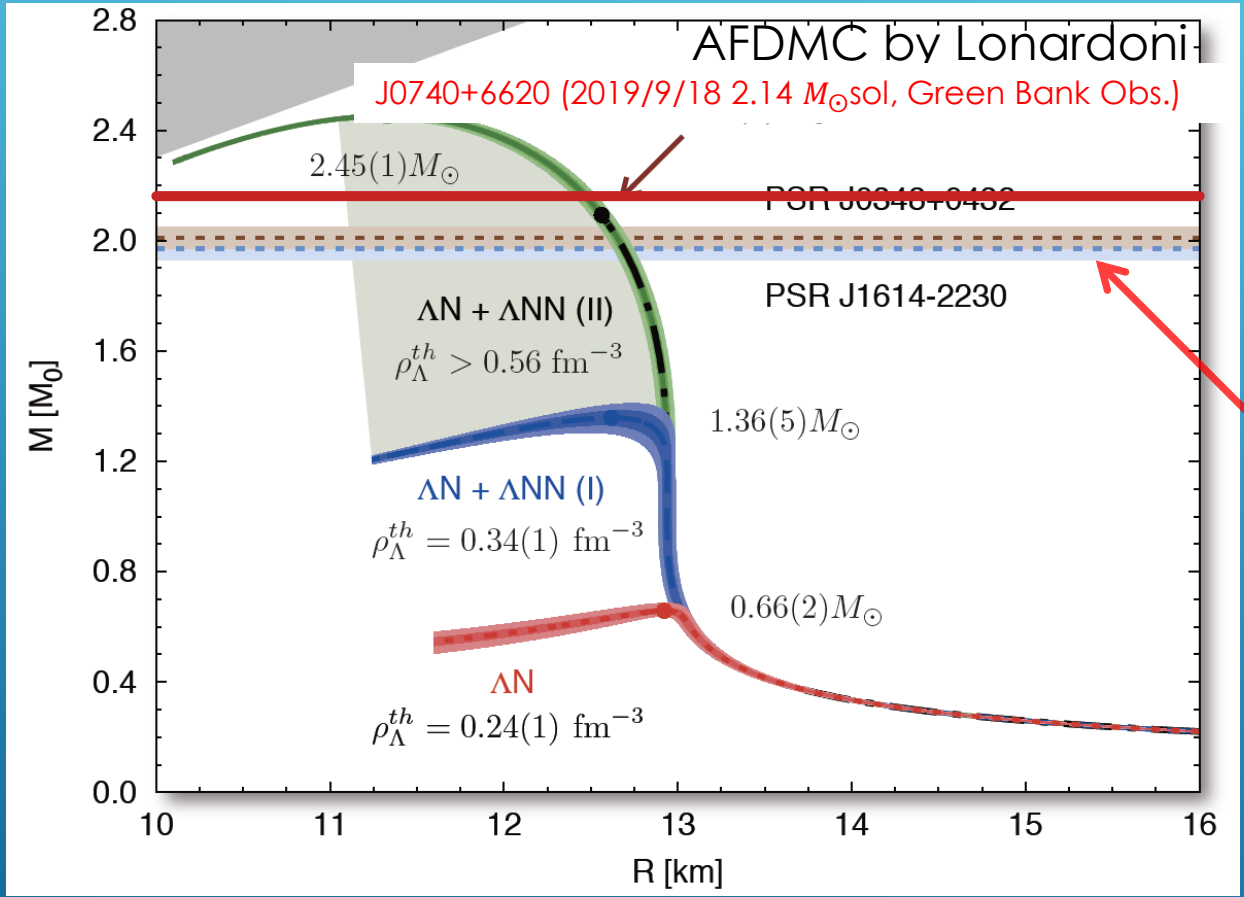
HYPERON PUZZLE

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

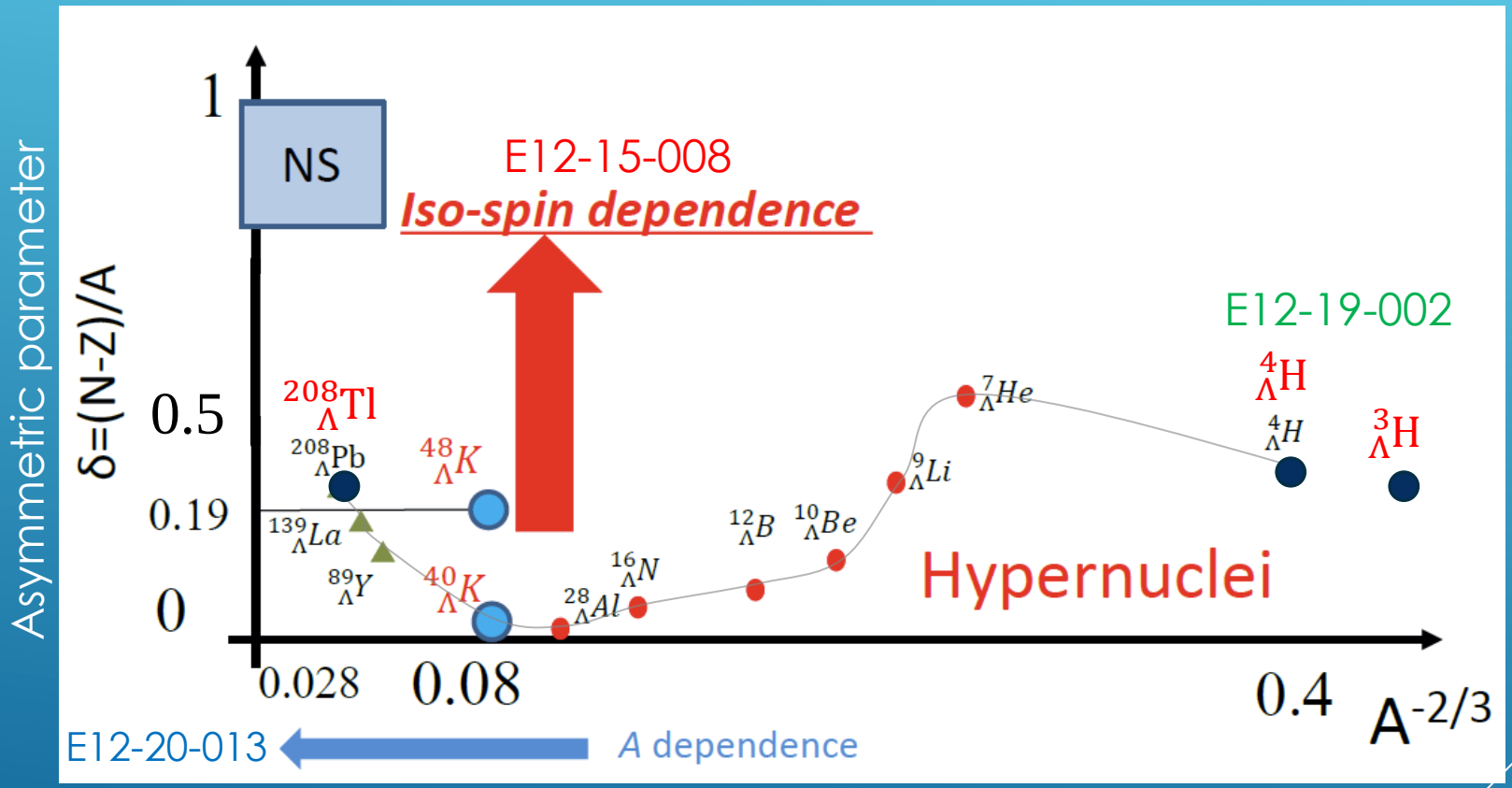
Additional Force to make EOS stiff

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

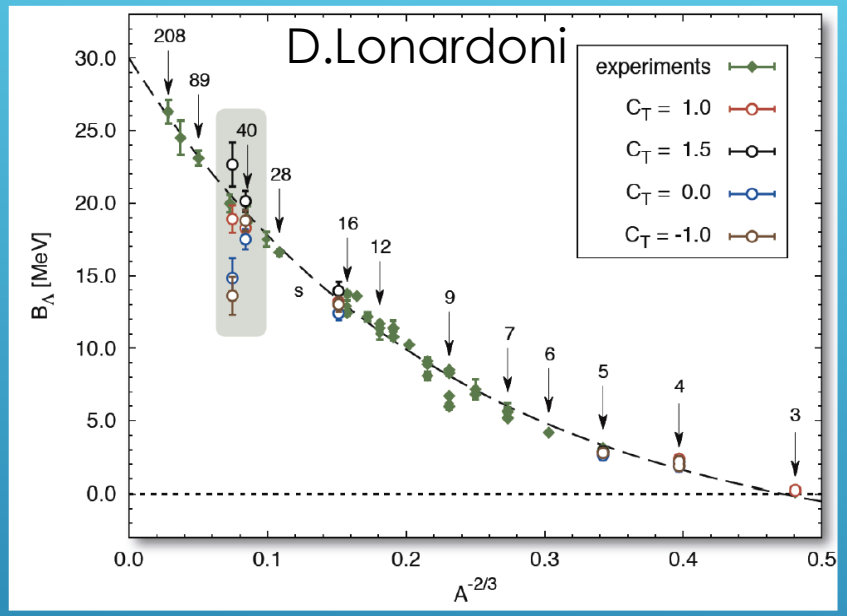
ESC08c + 3B/4B RF : G-Matrix Calc. by Yamamoto et al., PRC 90 (2014) 045805.

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

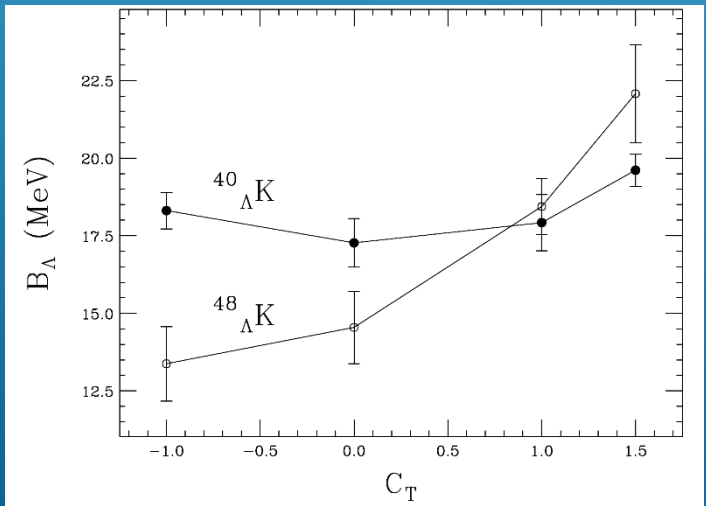
From Hypernuclei to NS



PHENOMENOLOGICAL 3 BRF+AFDMC



C_T :Parameter to gauge Λnn contribution in ΛNN potential

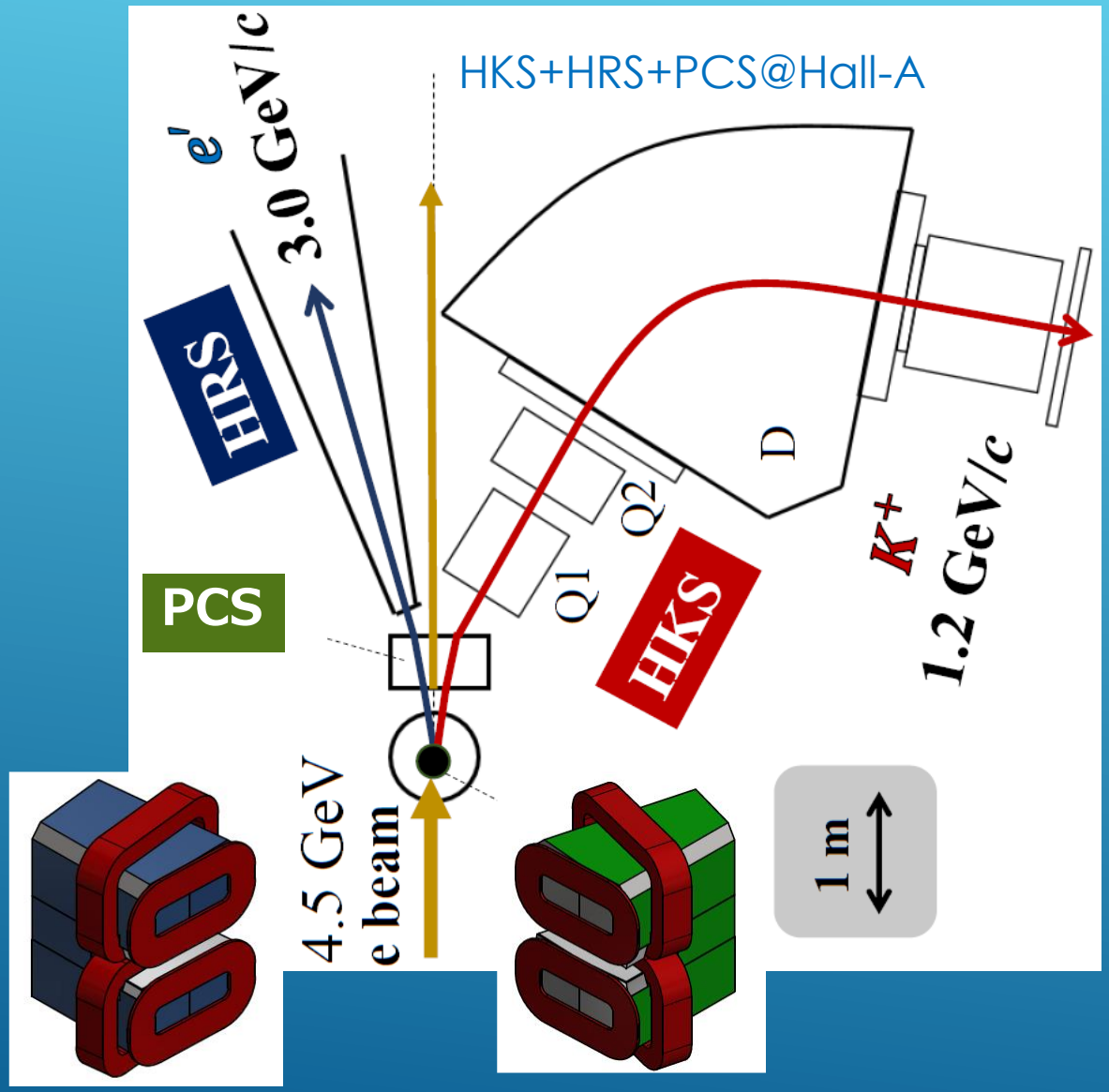


^{40}Ca(e ,e′K$^+$)$^{40}_{\Lambda}$K and , ^{48}Ca(e, e′K$^+$)$^{48}_{\Lambda}$K

E12-15-008
accepted with GRADE A.

E12-15-008 ($^{40,48}_{\Lambda}$Ca), E12-20-013 ($^{208}_{\Lambda}$Pb)

2020/3/13 @ TOKIN (SENDAI)

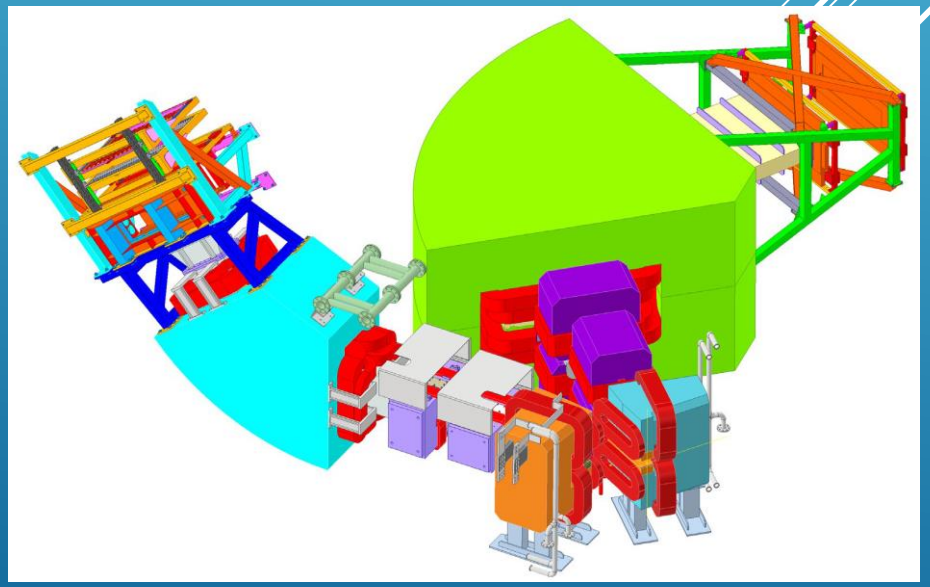


New Pair Charge Sep. Mag.

^{40,48}Ca targets

GEANT4 Simulation: T. Akiyama
Solid target design: Y.R.Nakamura

HKS+HES+PCS@Hall-C



HYPERTRITON ($^{3}_{\Lambda}$H) PUZZLE

T.Gogami JLab PAC49

E12-10-002 Approved by PAC49

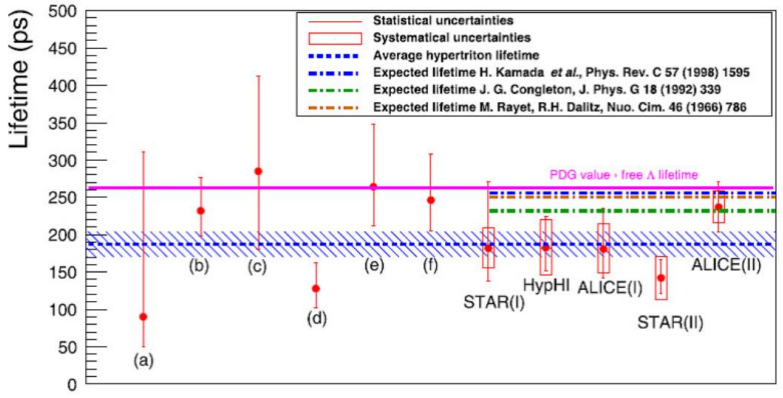
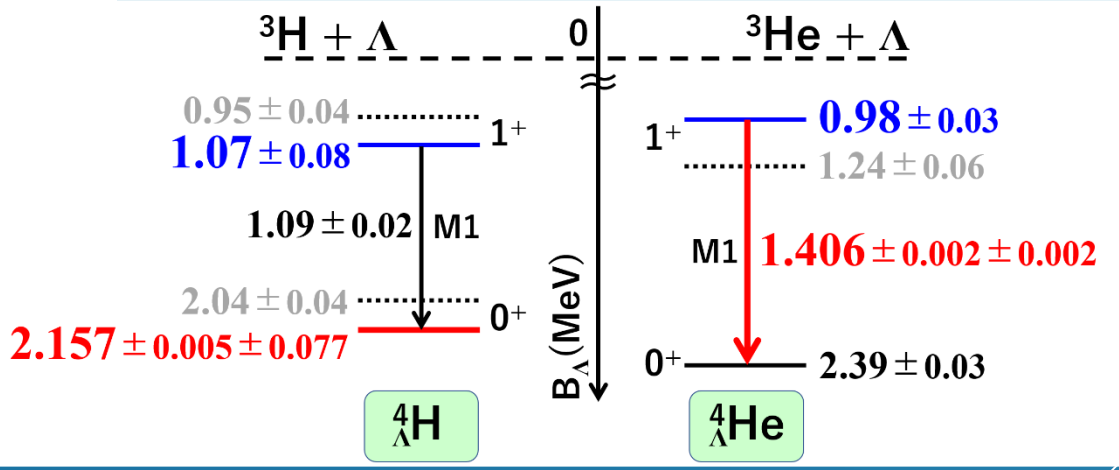


FIG. 2. Lifetime of Λ hypertriton summarized in Ref. [21]. Experimental data labeled as obtained in bubble chamber and emulsion experiments.

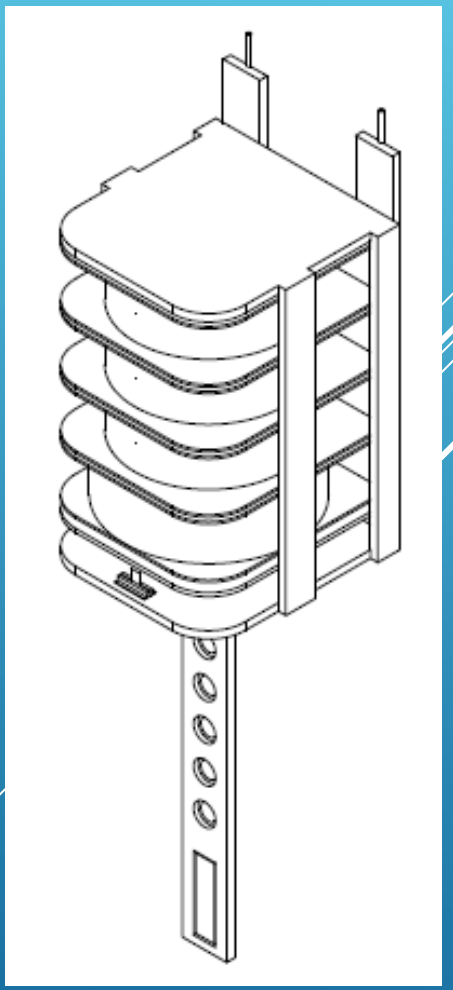
T.Gogami et al.
JLab E12-10-002 Proposal (2021)

Introduction of
Cryogenic Gas Targets

Short lifetime contradicts
to shallow binding



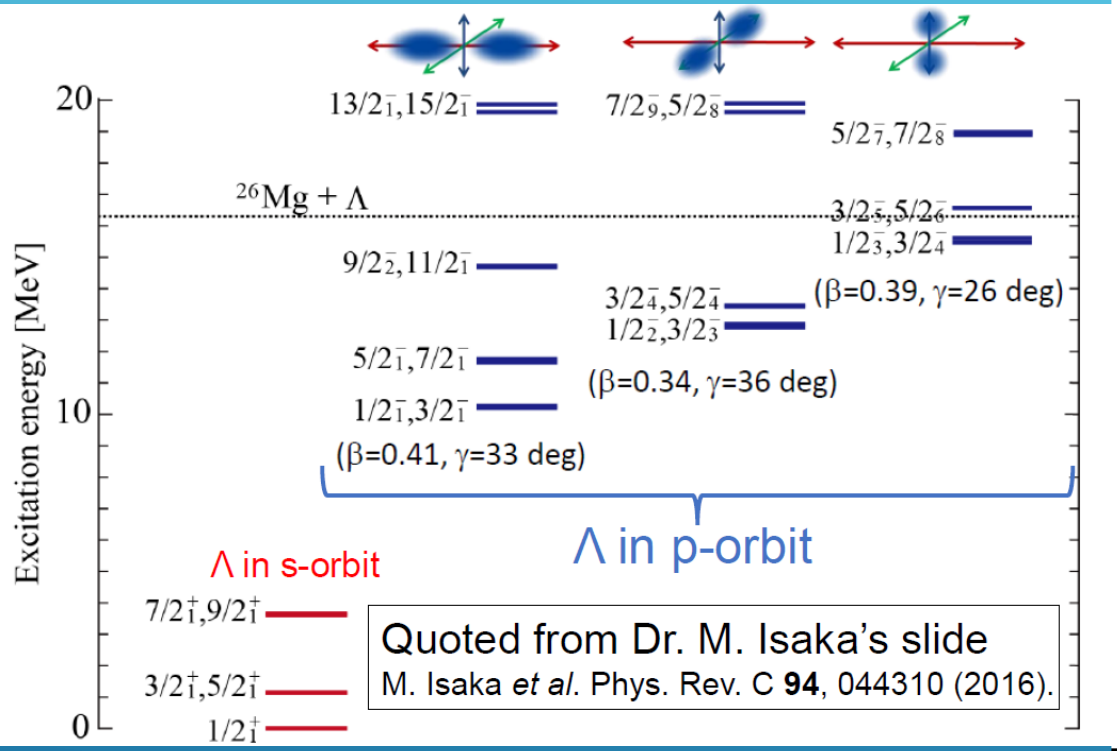
中村、永尾、田村、山本　物理学会誌に寄稿



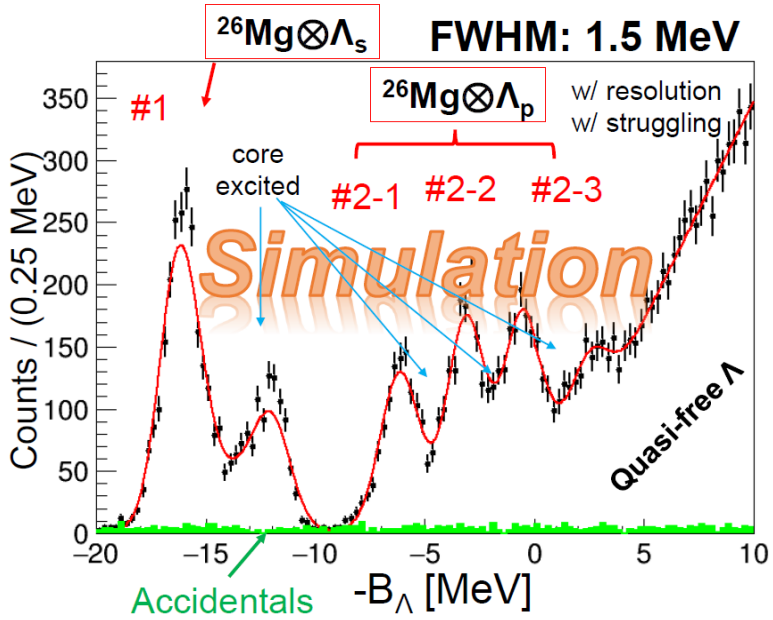
$^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H Spectroscopy

$|\Delta B^{\mathrm{stat.}}| = 20$ keV, $|\Delta B^{\mathrm{sys.}}| = 55$ keV

Is ^{26}Mg a triaxial deformed nucleus?



^{27}Al(e,e'K$^+$)$^{27}_{\Lambda}$Mg: Expected Spectrum @20μA



- 12 days for ^{3}He+Al (E12-19-002)
- ^{27}Al cell: 0.37 mm thick

Simulation input from HyperAMD

#1 B_Λ = 16.3 MeV : ^{26}Mg⊗Λ$_s$

#2-1 B_Λ = 6.3 MeV : ^{26}Mg⊗Λ$_p$ 1st
#2-2 B_Λ = 3.3 MeV : ^{26}Mg⊗Λ$_p$ 2nd
#2-3 B_Λ = 0.8 MeV : ^{26}Mg⊗Λ$_p$ 3rd

p-orbit splitting due to the triaxial deformation

ΔB_Λ (stat.) = 20 keV

K.Okuyama @ ストレンジネス核物理の将来を考える研究会,
Sep. 21, 2021

$$^{27}\mathrm{Al}(e, e'K^+)^{27}_{\Lambda}\mathrm{Mg}$$

SUMMARY

- (e,e'K^+) opens a door of sub-MeV spectroscopy of Λ hypernuclei at JLab.
- Experiment of $^3H(e, e'K^+)X$: Upperlimit for Λnn states
  Λn FSI analysis in progress.
- New programs: Hypertriton puzzle and CSB study ($^3_\Lambda H$, $^4_\Lambda H$),
  Tri-axial deformed hypernucleus ($^{27}_\Lambda Mg$)
  Isospin dependence ($^{40}_\Lambda K$, $^{48}_\Lambda K$),
  Heaviest hypernuclei ($^{208}_\Lambda Tl$)

Hall-A (Good S/N, moderate Res.) vs Hall-C (Good Res., mod. S/N)

Complementary to (π,K^+) Spectroscopy at HIHR