Additional Beamtime Request
Due to **relocation from Hall-A to Hall-C**
For E12-15-008
(put on the jeopardy list in 2023 and reapproved by PAC51)

PR12-24-013

An isospin dependence study of the Lambda-N interaction through the high precision spectroscopy of Lambda hypernuclei with electron beam

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Univ. of **Tokyo** ; Moved from Tohoku
JLab Hypernuclear Collaboration

HYPERON Puzzle

Mystery of heavy Neutron Stars.

Based on our knowledge of baryonic force,
Hyperon naturally appear at high density ($\rho \sim 2{,}3\rho_0$)

⇩

Too soft EOS. **NS cannot support mass of 2 $M_\odot$**

⇩

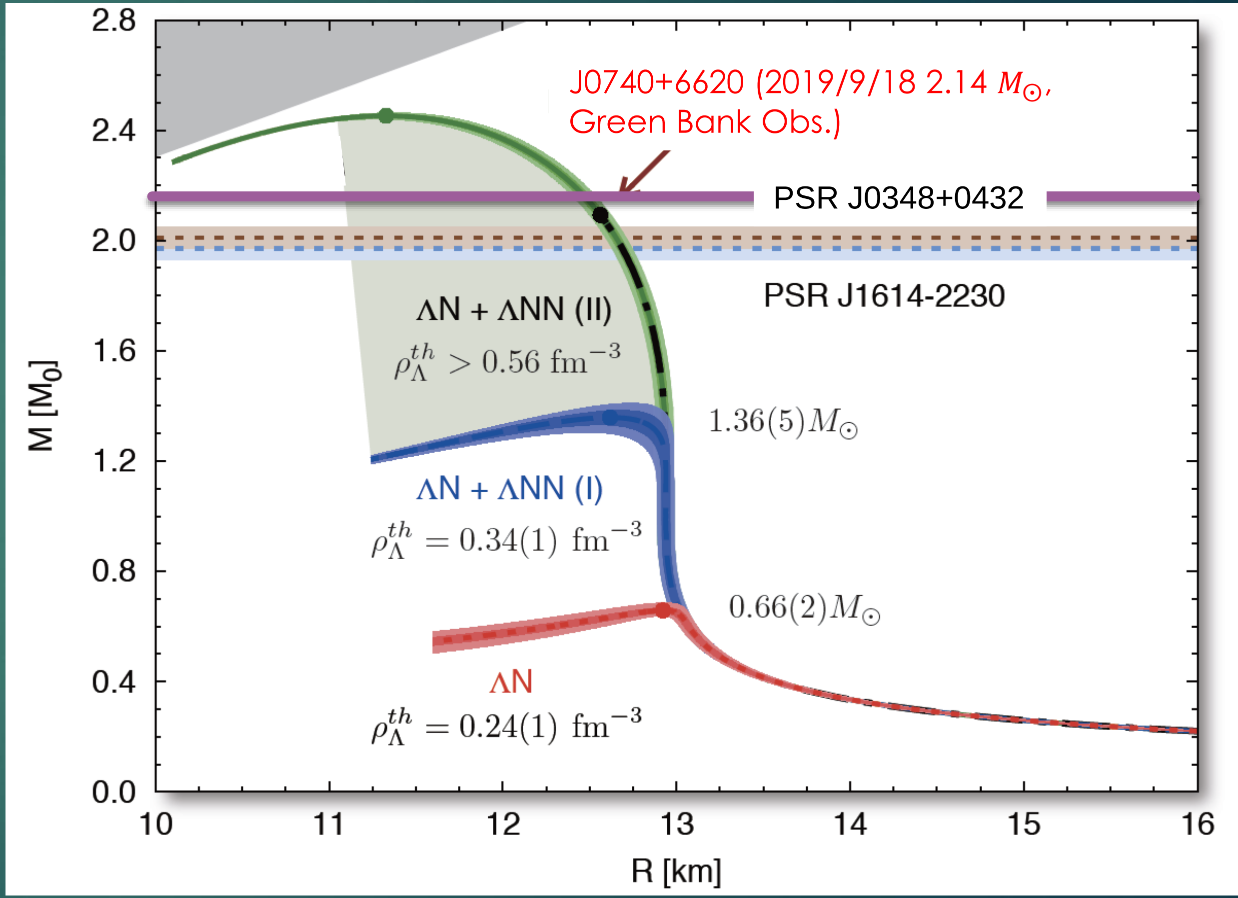
Contradict to astronomical observations.

⇩

Need **additional repulsive force**
(ΛNN 3-body repulsive force)
Make stiffer EOS

⇩

Neutron star : **Large $(N-Z)/A \geq 0.9$ and Large A**



2 solar mass NS

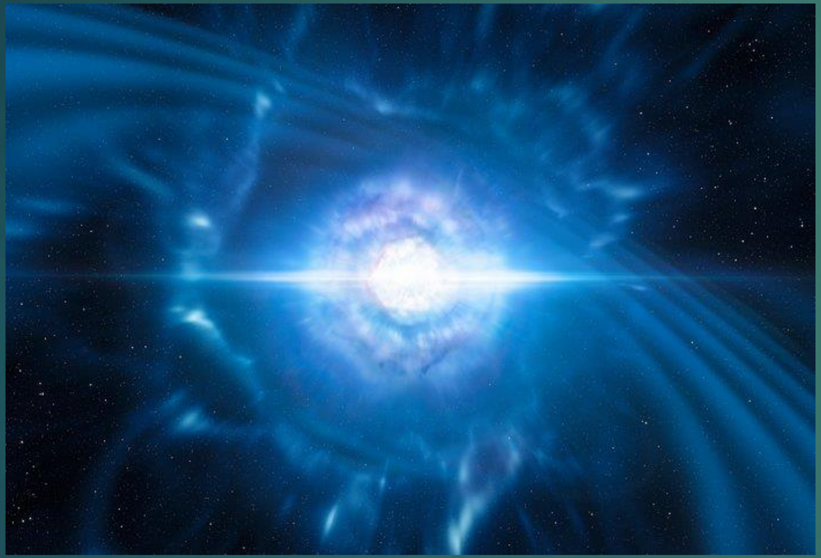
Iso-spin dependence
E12-15-008+PR12-24-014

A dependence
E12-20-013+PR12-24-003

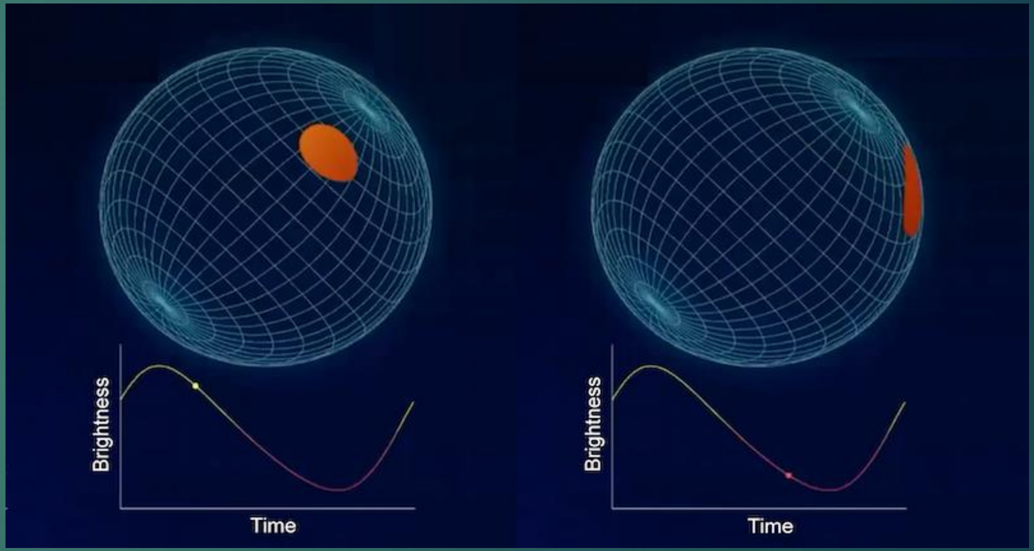
New astronomical observations

New Gravitational Waves from NS mergers and NICER (Neutron star Interior Compsition ExploreR)

CC4.0 ESO/L. Calçada/M. Kornmesser



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

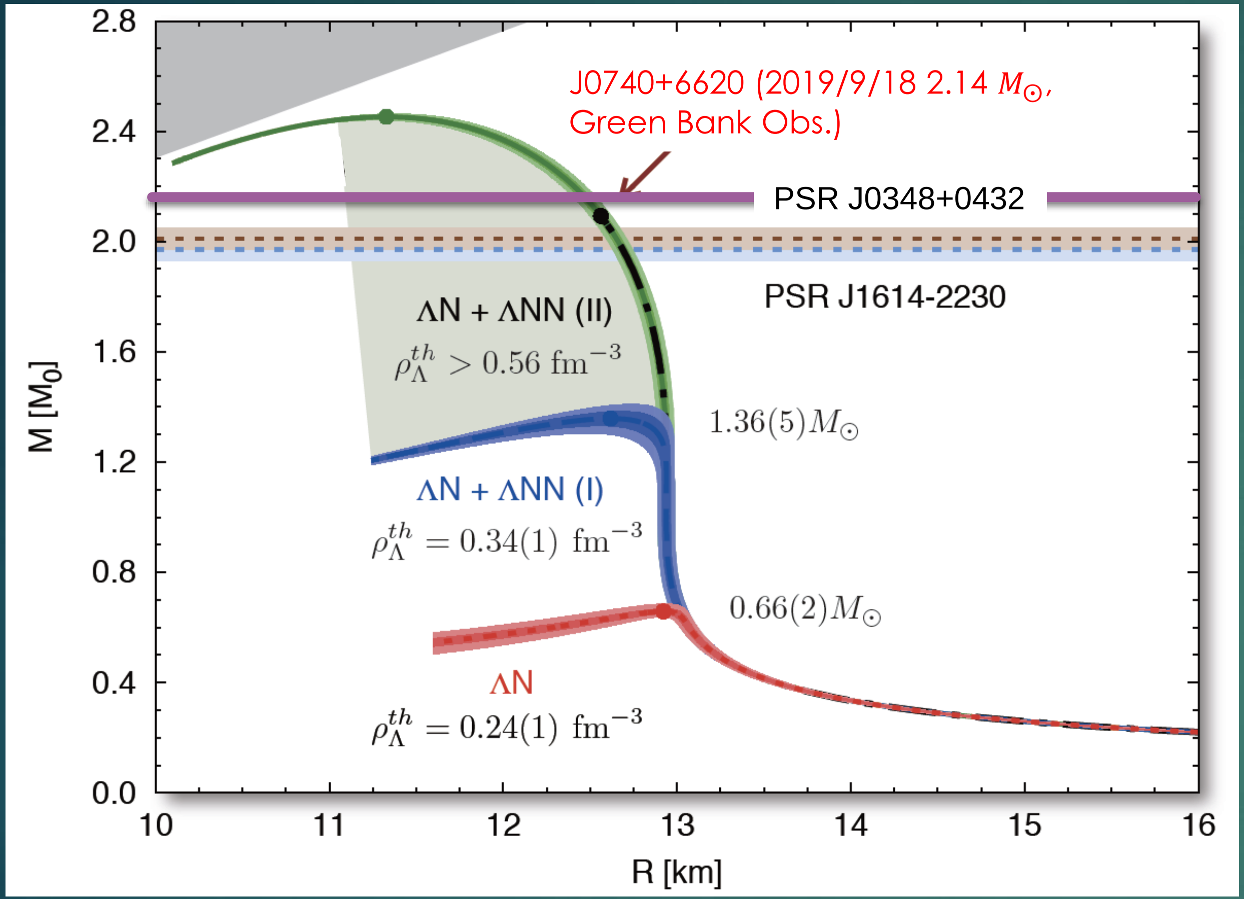


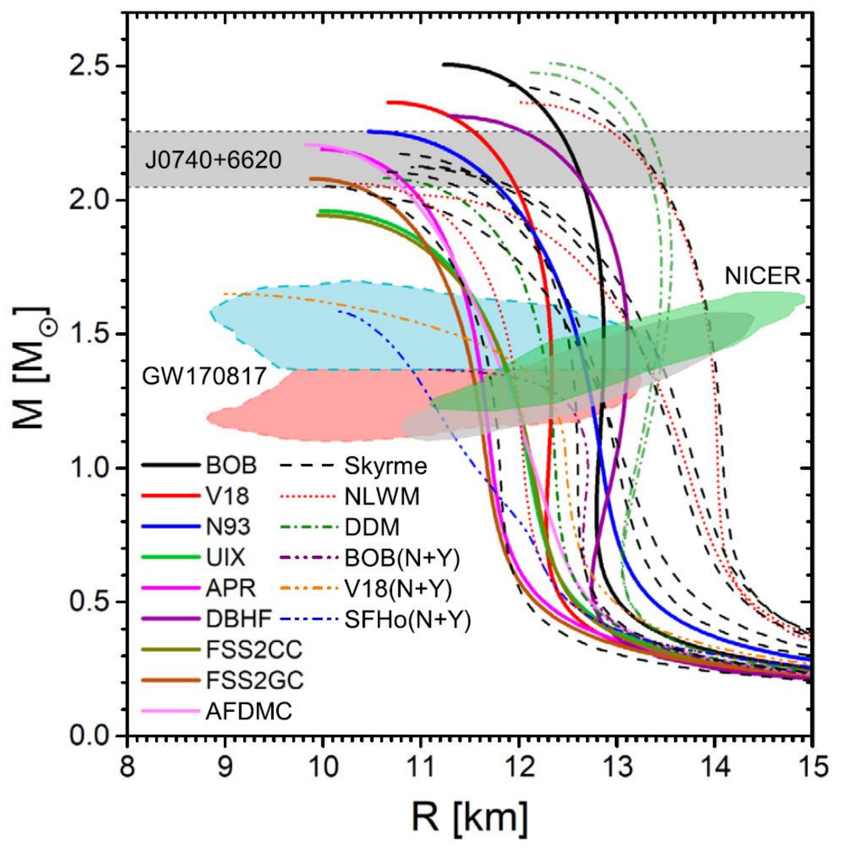
Goddard Space Flight Center

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

Macropscopic features of NS : Tidal deformability, Radius and Mass

New constrains from astronomical observations





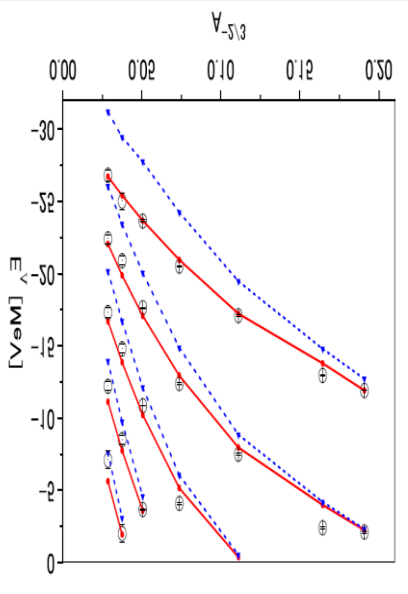
C.F.Burgio et al. Prog. Part. Nucl. Phys 120 (2021) 103879.

Macroscopic understanding of NS made great progresses.
But we would like to know why NS is so heavy and large.

Microscopic study (nuclear physics exp) becomes more important than ever!

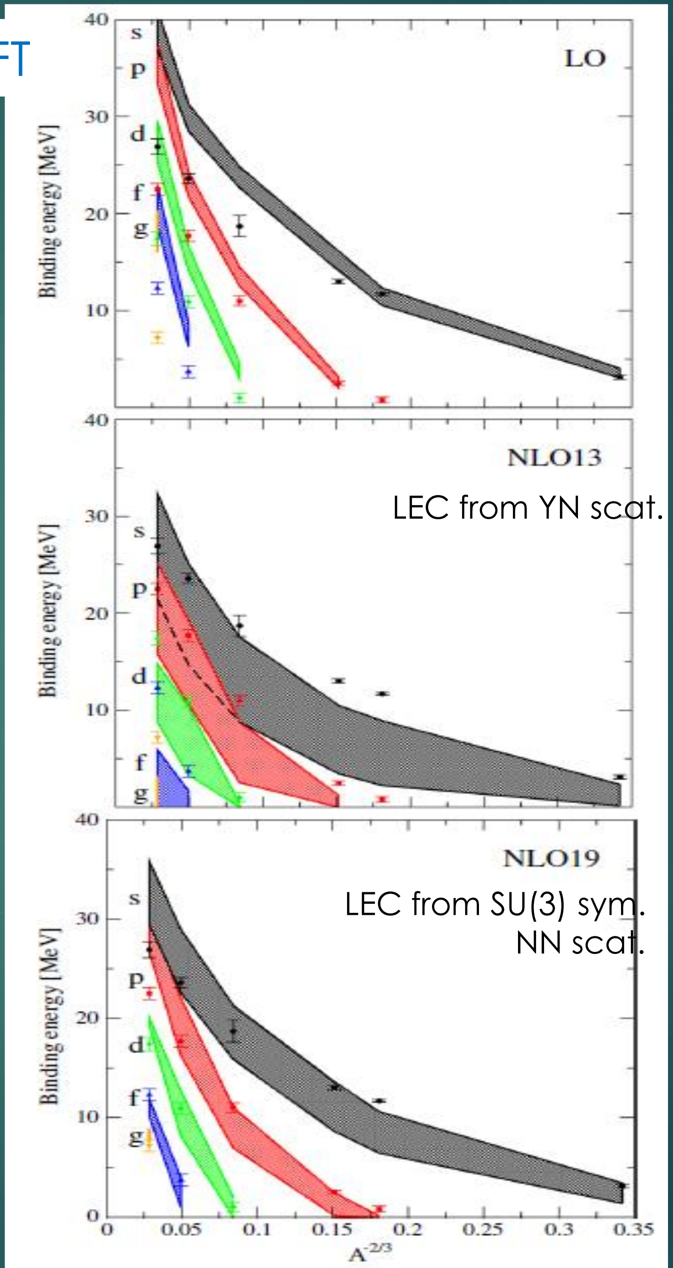
Λ Single Particle Energies of Λ Hypernuclei by Various Calculations

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



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

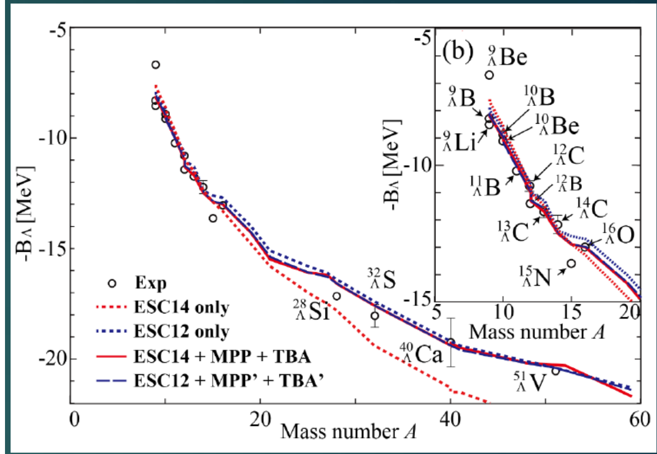
ChEFT



LEC from YN scat.

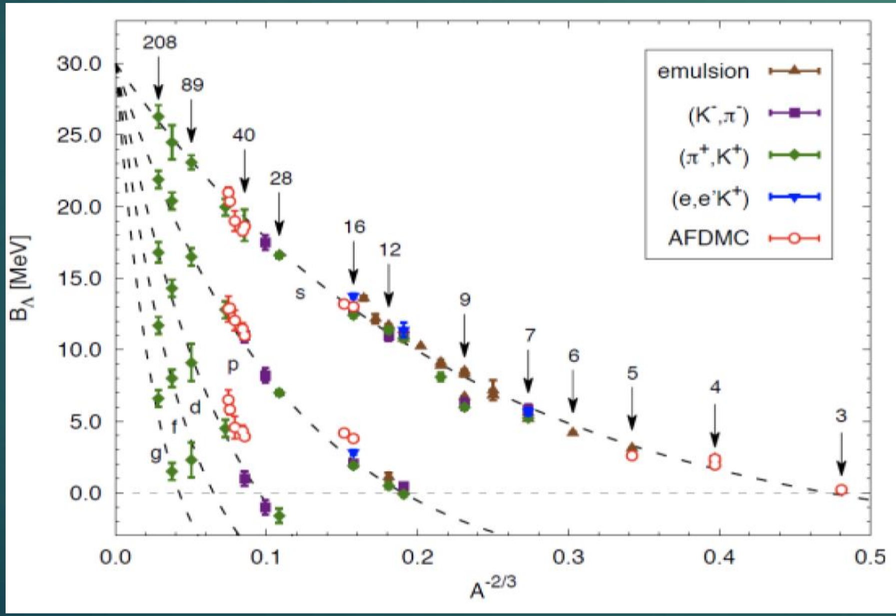
LEC from SU(3) sym.
NN scat.

Hyper-AMD



M.Isaka et al.,
PRC94, 044310 (2016),
PRC 95, 044308 (2017)

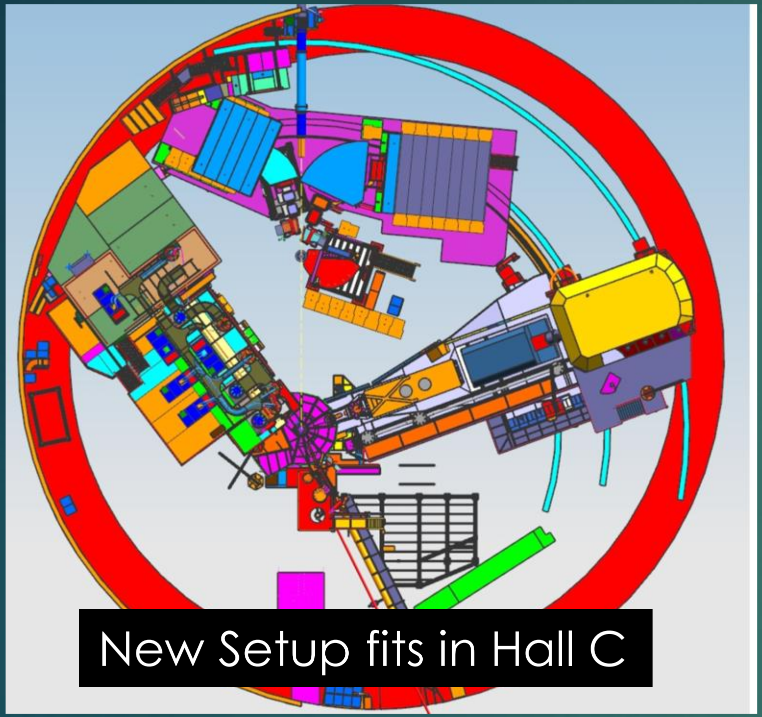
AFDMC

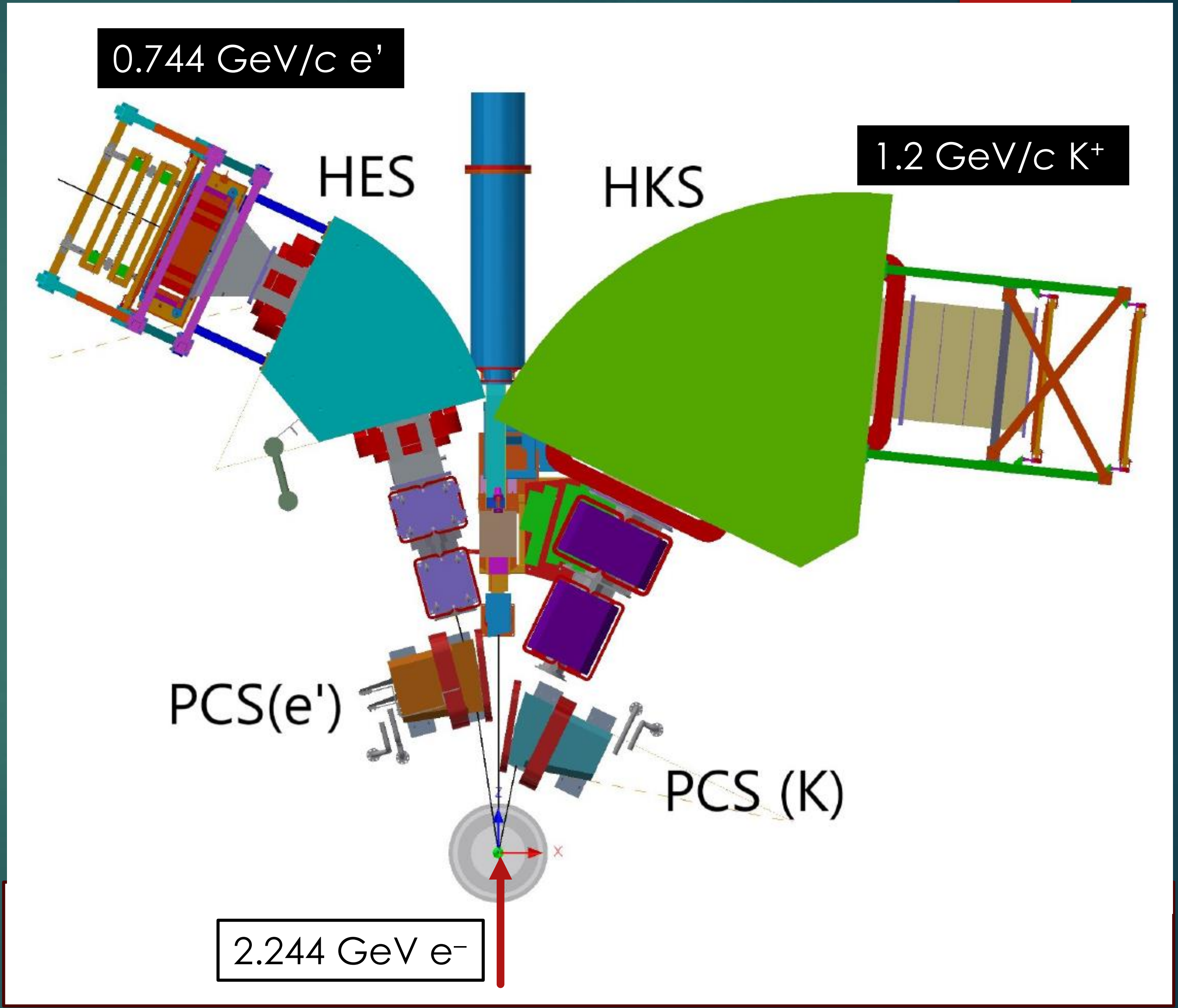


D.Lonardoni and F. Pederiva, arXiv:1711.07521.

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

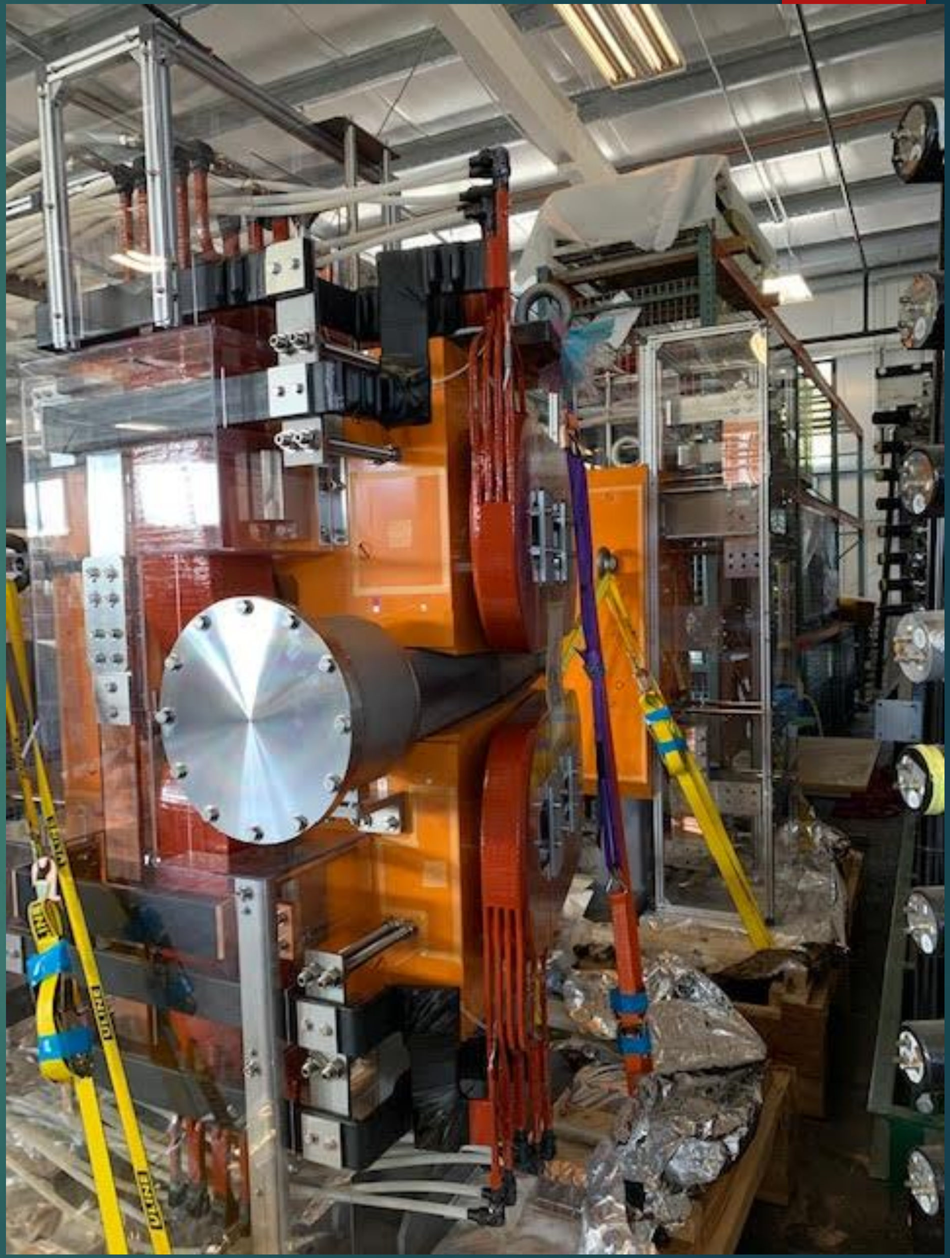
Setup in Hall-C



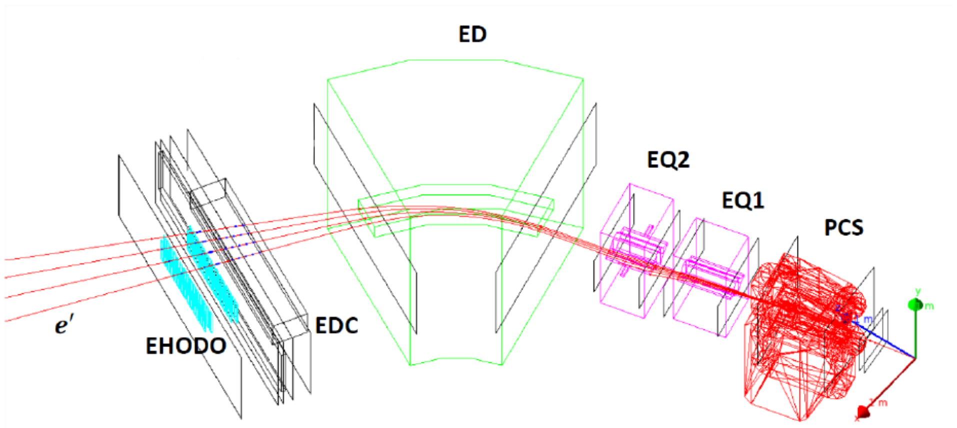


PCS magnets, newly developed major instrument, were already constructed and shipped to JLab

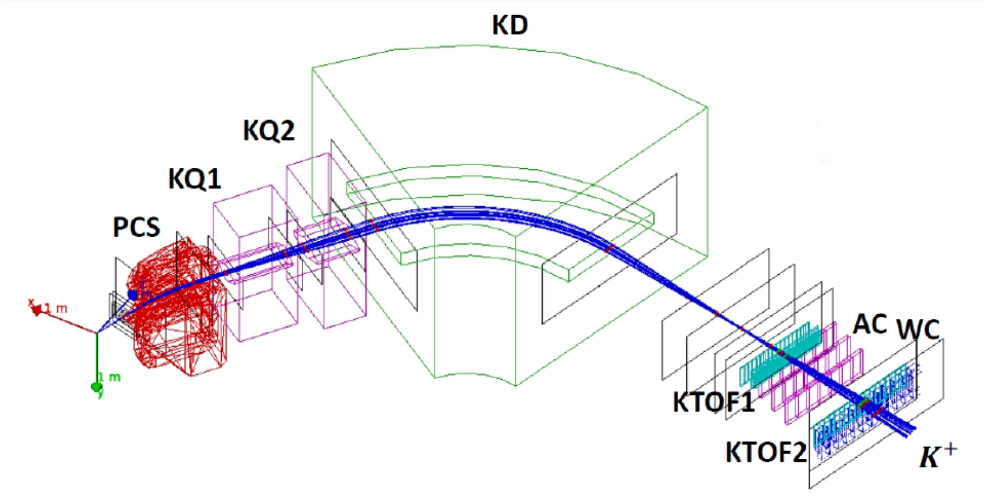
Newly constructed PCS magnets (TOKIN, 2020.3)



Delivered to JLab (2022.2 @ JLab)



(a) The model of HES implemented in GEANT4.

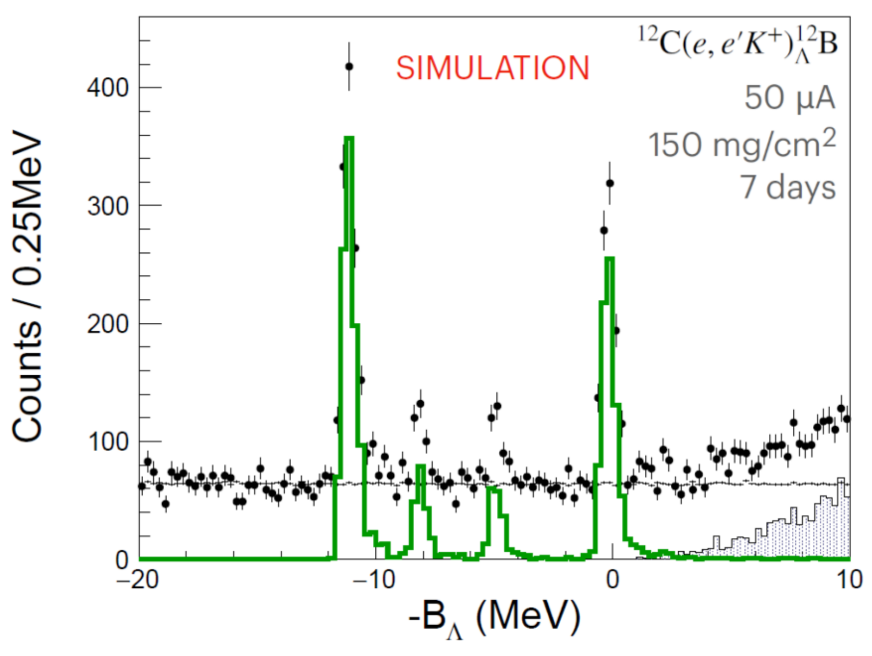


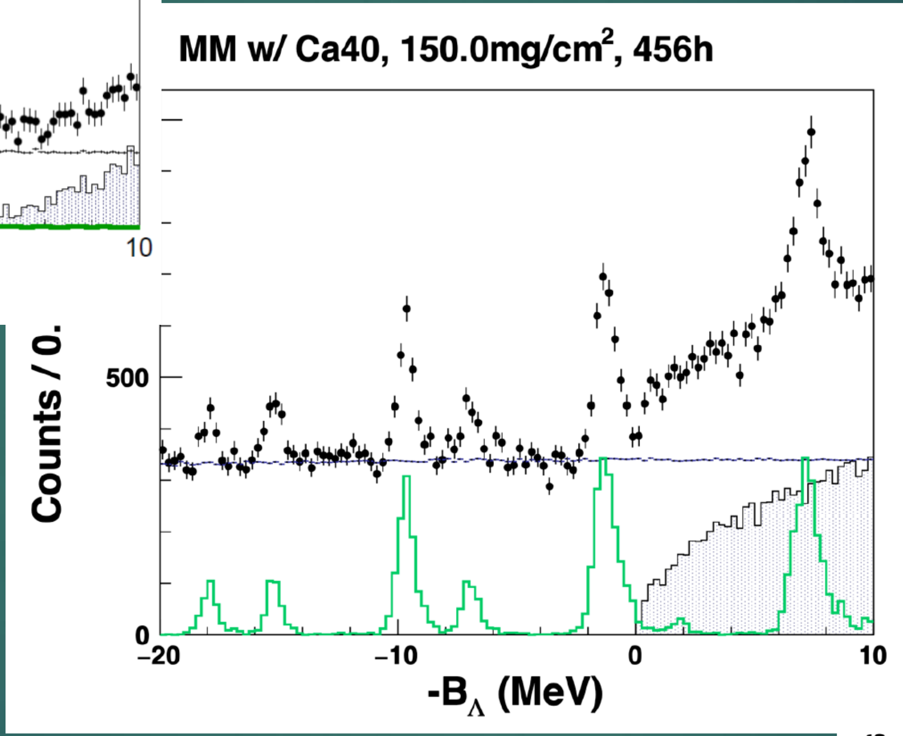
(b) The model of HKS implemented in GEANT4.

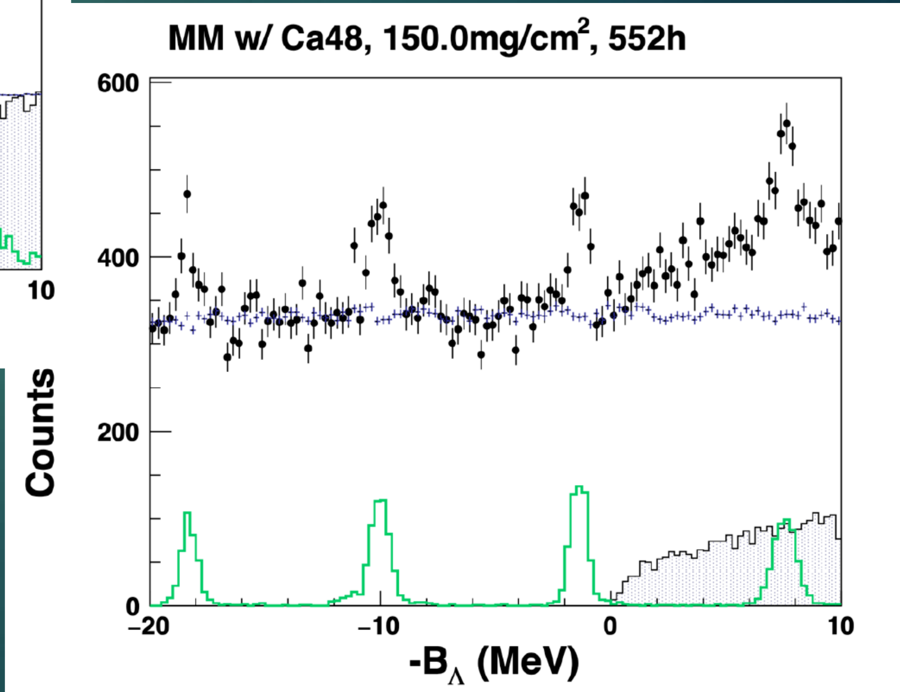
Beam	Energy E_e [/(GeV)]	2.240
	Energy stability $\Delta E_e/E_e$	$< 1 \times 10^{-4}$(FWHM)
PCS + HES	Central momentum P_e [/(GeV/c)]	0.744
	Central angle $\theta_{e,e'}$ [/(deg)]	8.5
	Solid angle $\Delta\Omega_{e'}$ [/(msr)]	3.4
	Momentum resolution $\Delta P_{e'}/P_{e'}$	4.3×10^{-4}(FWHM)
PCS + HKS	Central momentum P_K [/(GeV/c)]	1.200
	Central angle θ_K [/(deg)]	11.5
	Solid angle $\Delta\Omega_K$ [/(msr)]	7.0
	Momentum resolution $\Delta P_K/P_K$	2.9×10^{-4}(FWHM)
p $(e, e'K^+)$ Λ	W [/GeV]	1.912
	Q^2 [/(GeV/c)^2]	0.036
	$\theta_{\gamma^* K}$ (/deg)	7.35
	ϵ	0.59
	ϵ_L	0.0096

Detailed GEANT4 Simulation incl. PCS

Expected missing mass spectra for $^{12}_{\Lambda}B$, $^{40}_{\Lambda}K$, $^{48}_{\Lambda}K$





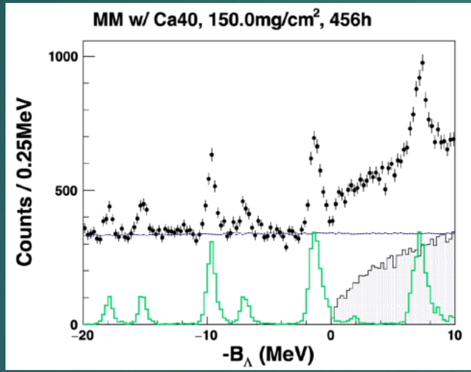


Expected resolution 0.6 MeV (FWHM)

Estimation of Necessary Beamtime

GEANT4 Simulation

Expected Spectra

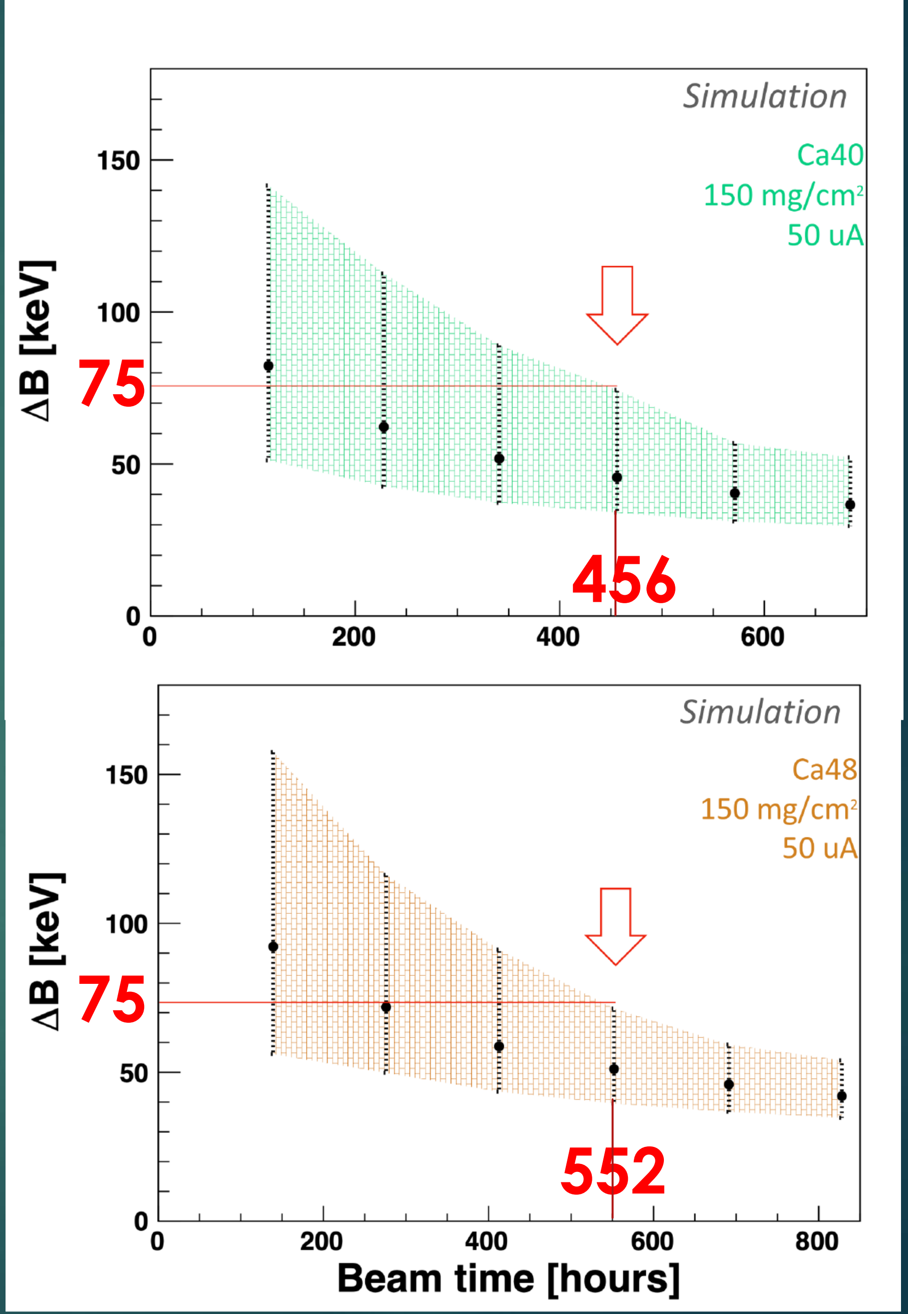


Mixed Event Analysis(BG subtraction)

X 1000

Peak Fit

Energy Determination Uncertainty ΔB



Summary of updated request of beamtime

Target (Hyper Nucleus)	Beam current (μA)	Target thickness (mg/cm^2)	Assumed cross section (nb/sr)	Expected yield (/h)	Num. of events	Req. beamtime (hours)	B.G. rate (/MeV/h)	S/N	Comments
CH_2 (Λ, Σ^0)	2	450	1000	6.12	890	144	0.02	475	Calibration
^{12}C ($^{12}_{\Lambda}$B)	50	150	90	5.39	900	168	0.85	8.4	Calibration
^{27}Al ($^{27}_{\Lambda}$Mg)	50	150	40 *	1.06	180	168	1.25	1.1	Calibration
Subtotal						480			Calibration
^{40}Ca ($^{40}_{\Lambda}$K)	50	150	50	0.90	410	456	1.70	0.7	Physics
^{48}Ca ($^{48}_{\Lambda}$K)	50	150	50	0.75	410	552	1.34	0.7	Physics
Subtotal						1008			Physics
Total						1488			

* for $0s^{\Lambda}$ $9/2^+, 7/2^+$ doublet.

1488 hours (62 days) beamtime (28 days were already approved as E12-15-008 by PAC51)

Requesting extension of **34 days**

7 days calibration can be absorbed in PR12-24-011 if it is approved.

Answer to TAC question

Need $2.24\ \text{GeV} \times (3 \times 10^{-5}) = 70\ \text{keV}\ (\sigma)$ beam **stability** for our goal.

If beam stability is **worse than our expectation**, will try **correction based on SLI**.

If this **correction does not work**, we will **mark data of unstable beam periods and exclude them from analysis**.
Frequent energy calibration may help to control the long-term beam stability issue.

Contribution of energy spread to MM should be less significant than scattered electron, kaon momentum resolutions.
P(e') = 0.744 x 4.3e-4 = 320 keV/c (FWHM) = 140 keV/c(sigma)
P(K+) = 1.2 GeV/c x 2.9e-4 = 350 keV = 150 keV/c (sigma)

Spread of 3×10^{-5}**(σ = 70 keV for 2.24 GeV) is desirable** and
100 keV = 4.5×10^{-5} for 2.24GeV might be tolerable.
It should be noted that the
beam spread cannot be corrected in the analysis.

Summary

- **High-precision hypernuclear spectroscopy is more important** at the time of PAC44 due to recent progresses of astronomical observations.
- Redesigned the approved Hall A experiment for Hall C. Detailed simulations confirmed that the **initial physics results can be achieved** with the **revised kinematic conditions and required beam time**.
- **All necessary spectrometer including newly developed PCS magnets are ready in hands**.
- We **request 1488 hours (62 days) beamtime (28 days were already approved as E12-15-008; Requesting extension of 34 days; 7 days calibration can be absorbed in PR12-24-011 if it is approved)** .
- The experiment aims study ΛNN 3-body force iso-spin dependence study. It is essentially **important to solve the hyperon puzzle**.

Answers to Reviewers

- Q1. The proposal assumes the cross section of ^{40}Ca and ^{48}Ca is 50 nb/sr. Is this taken from the reference 69 (Umeya)? We cannot have an access to ref. 69, and would you please let us know why and how this and other cross sections were taken. In addition, how much is the ambiguity of the cross section of ^{40}Ca and ^{48}Ca ?
- A1. Umeya's calculation, based on the shell model plus DWIA, follows the same method used for the $^{12}_{\Lambda}B$ cross-section calculation performed by Motoba (JPS Conf. Proc. 17, 011003(2017)). Converting a proton of a closed shell target nucleus to a Lambda, a one-particle, one-hole state provides a good model to handle such a state, allowing for relatively reliable calculations. For the B12L ground state doublet, shell model calculations can reproduce the cross sections reasonably well for slightly different kinematics, as seen in E89-009, E01-011, and E05-115. Theoretical ambiguity is primarily influenced by the choice of elementary amplitudes for electro-production of Lambda. For example, the SLA and S6B models give differential cross sections of the 1-, 2- ground state doublet of $^{12}_{\Lambda}B$ as 100.4 nb/sr and 73.6 nb/sr, respectively, while the E05-115 result is 101 nb/sr. Therefore, we expect a similar ambiguity of 30% for ^{40}Ca and ^{48}Ca targets.

Answers to Reviewers

- Q2. ^{27}Al runs are requested for "backward transfer matrices tuning". Would you make clearer the reason why you chose ^{27}Al? I guess it might be because it has relatively larger cross sections for multiple levels and the target will be used another hypernuclear experiment?
- A2. We need a relatively light (small Z) solid target for the calibration, allowing for easy handling of targets and reduced electron background. As the referee pointed out, it is also a crucial characteristic for achieving a relatively large cross section for the ground state. Although the resolution was poor (as the experiment was not designed for high precision) and the target thickness was not controlled at all, we used the aluminum wall of the tritium target for calibration in the E12-17-003 experiment (nnL search in Hall-A). We have good experiences using aluminum targets and it is a natural choice to select ^{27}Al as the calibration target.

Answers to Reviewers

- Q3. For precise measurement, the stability of the spectrometer magnetic field might be important. How much stability is required and is it achievable?

- A3. The bending power (integral Bdl) of our spectrometers, HKS and HES, is primarily determined by dipole magnets. The specially prepared power supplies for HKS-D and HES-D are highly stable, with a current stability better than (1×10^{-5})/8 hours, except for an initial drift of 0.5 hours. We have established excitation procedures for the magnets to use the same point on the hysteresis curve. Furthermore, during experiments, NMR probes with a precision of 1×10^{-6} (1×10^{-5})/, monitor the stability of the dipole magnet field.

Answers to Reviewers

- Q4. Please answer to the TAC question about the beam energy stability, such as the desired energy stability over one hour, energy variation tolerable during a run, and desired energy spread.
- A4. Answered to TAC

- Q5. Beamtime request mismatch in abstract and Table 10.
- A5. 62 days of beamtime request is correct.