

# $\Lambda$ hypernuclear spectroscopy by S-2S at J-PARC and HKS at JLab

Kyoto University  
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December 10, 2021



**SPIRITS**  
SUPPORTING PROGRAM FOR INTERACTION-BASED  
INITIATIVE TEAM STUDIES

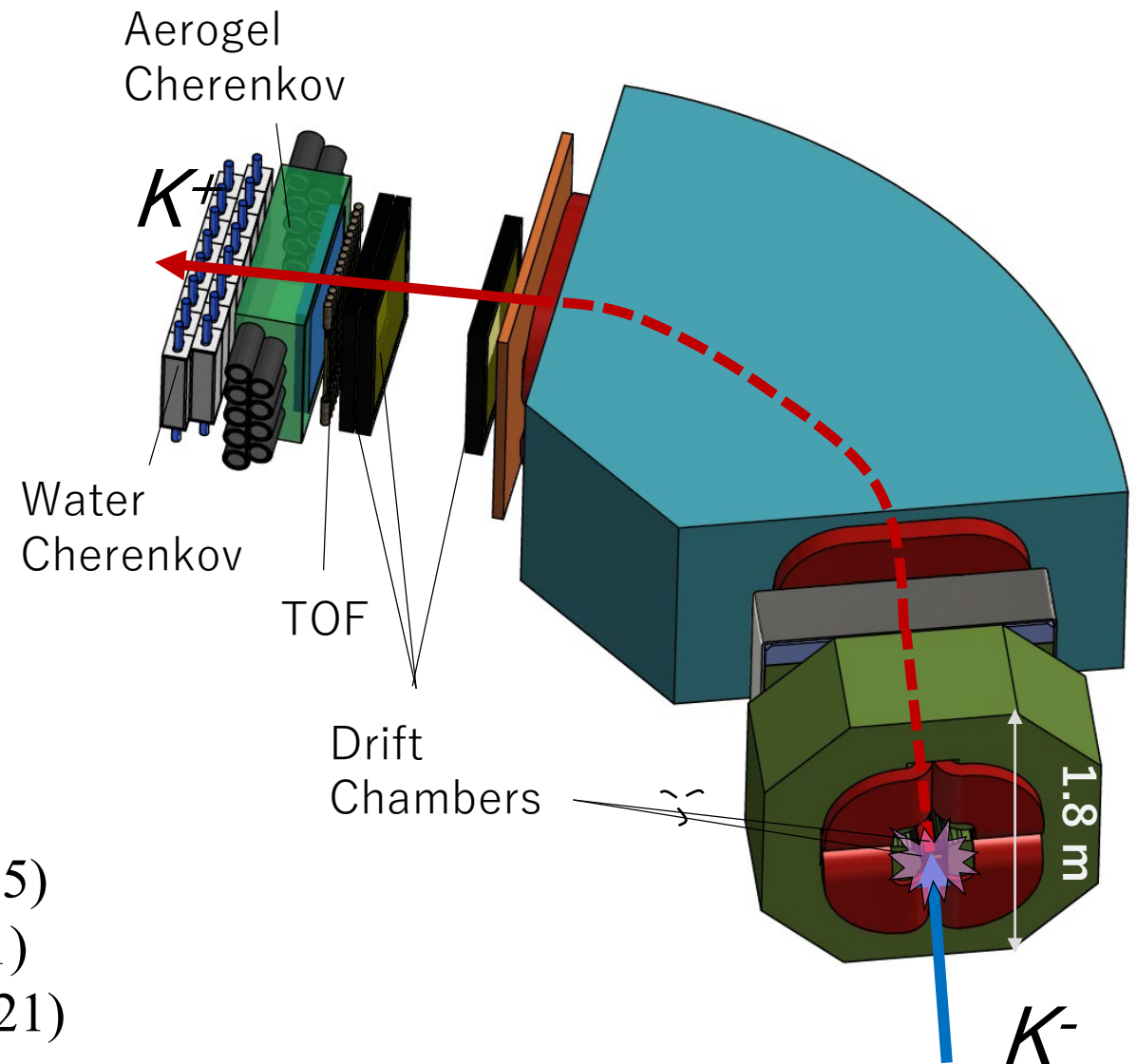
科研費  
KAKENHI

# J-PARC E70 ( $^{12}_{\text{E}}\text{Be}$ )

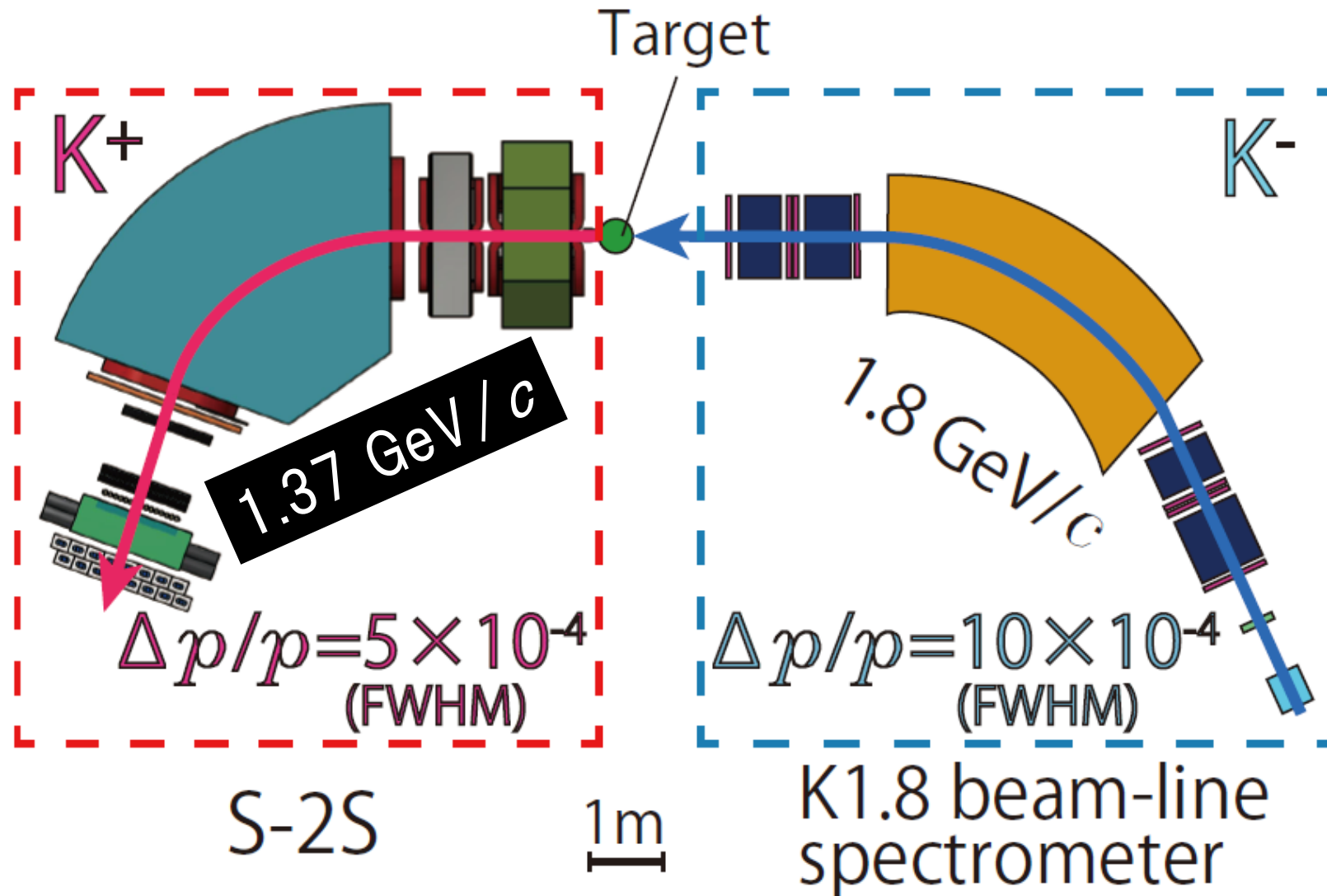
Missing mass experiment  
with  $^{12}\text{C}(K^-, K^+)$

c.f.) Emulsion studies:

- K. Nakazawa et al., PTEP 2015, 033D02 (2015)
- S. H. Hayakawa et al., PRL 126 062501 (2021)
- M. Yoshimoto et al., PTEP 2021, 073D02 (2021)

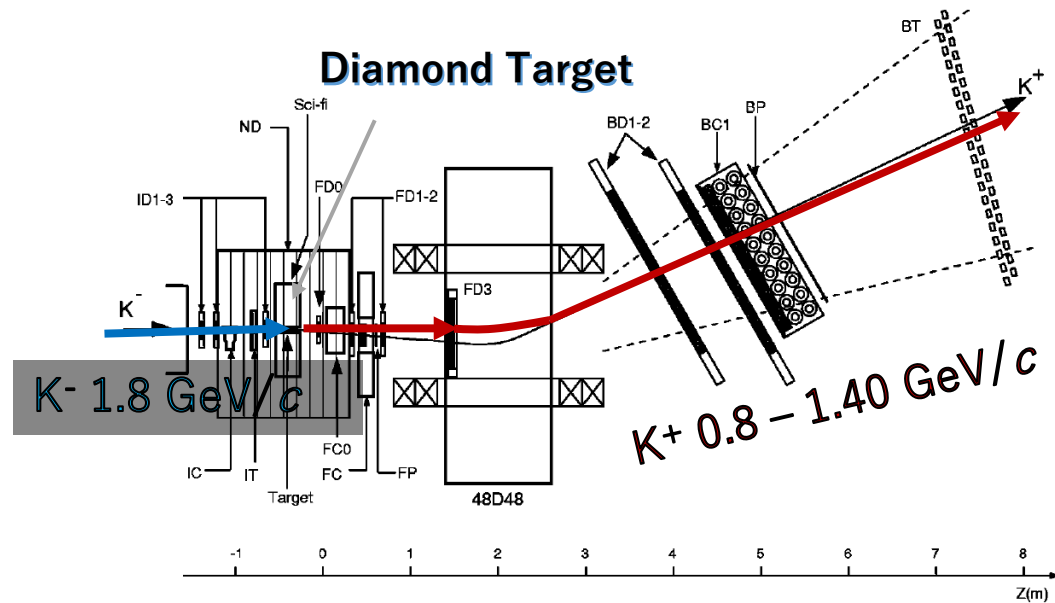


# J-PARC E70 w/ S-2S



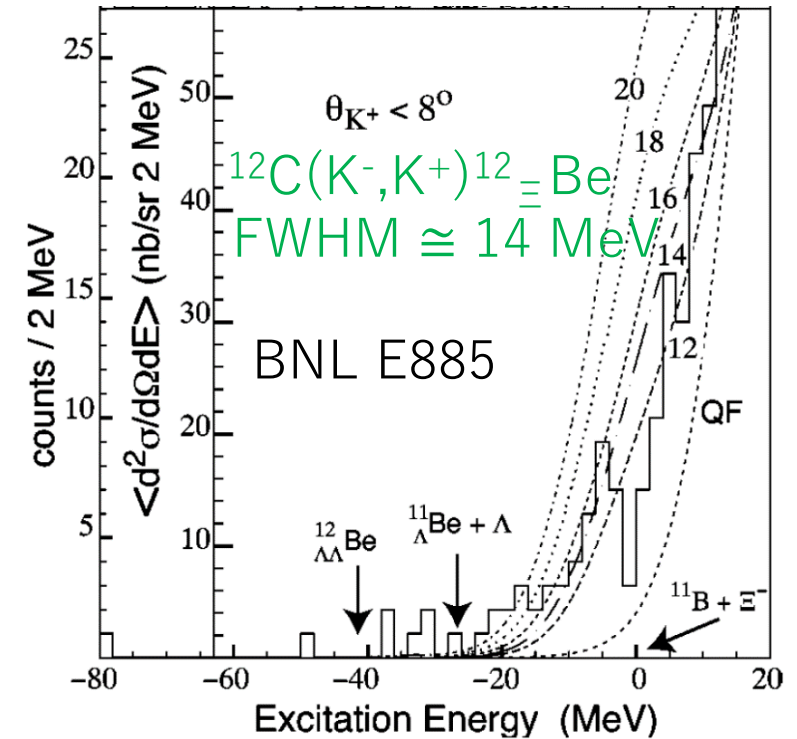
# Xi hypernuclear spectroscopy - BNL E885

P.Khaustov *et al.*, *PRC* **61** (2000) 054603



Experiment	KEK E224	BNL E885
FWHM (MeV)	22	14

➔ < 2 MeV in E70



$89 \pm 14$  nb/sr ( $\theta < 8$  deg)

$42 \pm 5$  nb/sr ( $\theta < 14$  deg)

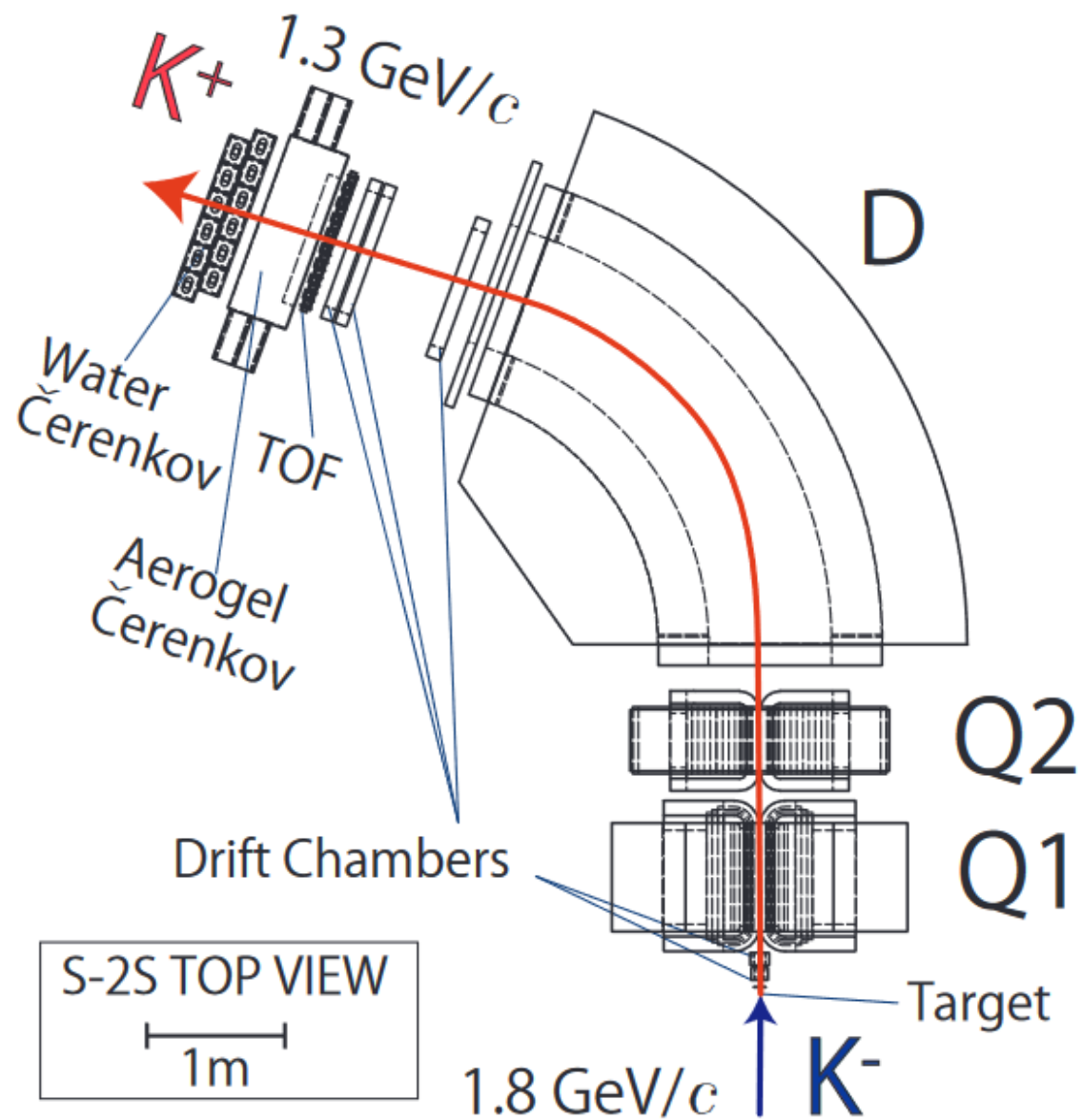
( $-20 < E_E < 0$  MeV)

➔  $V_{0E} \leq 14$  MeV



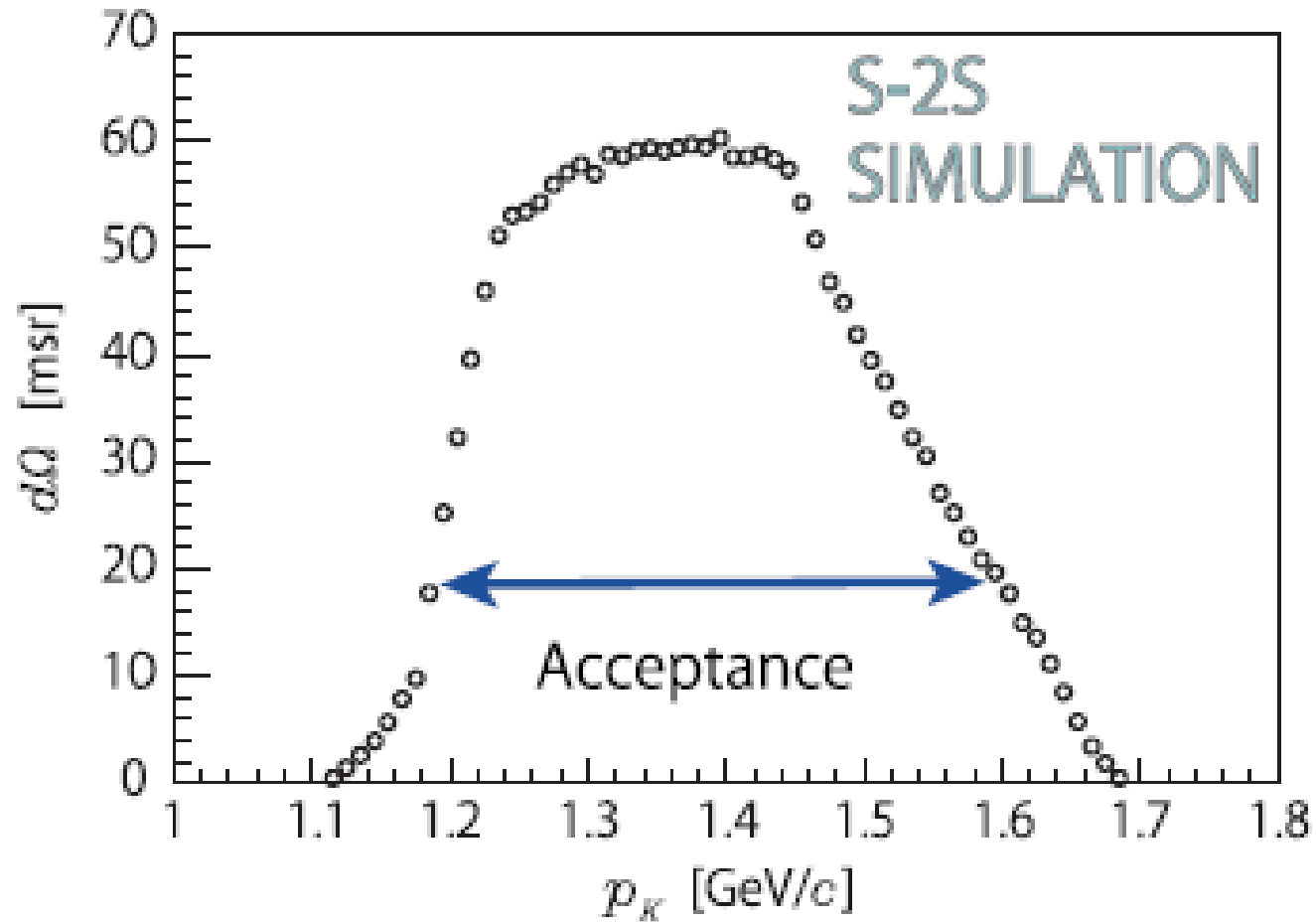
2022/1~4月にかけて磁石  
がインストールされる

# Detectors

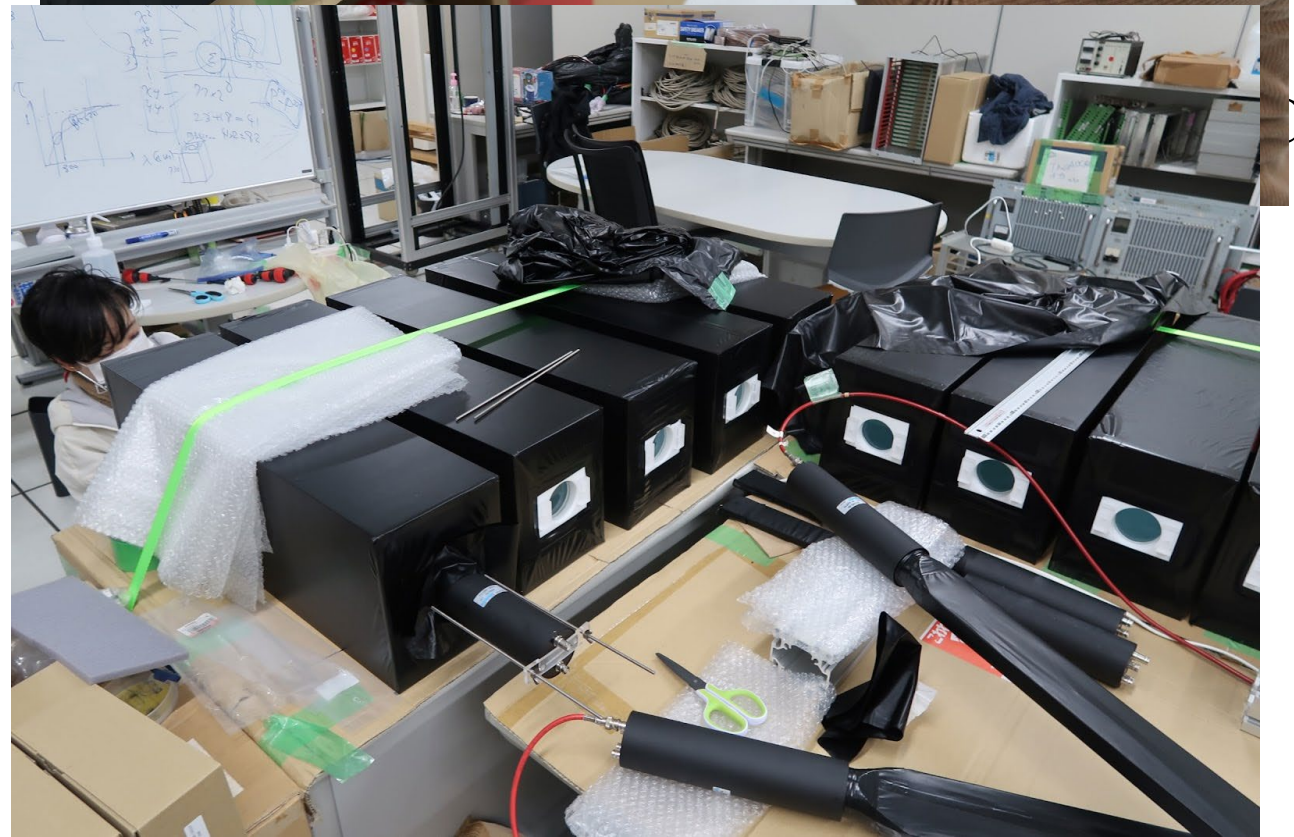


# S-2S Acceptance

TG et al., NIMA 817, 70—84 (2016)



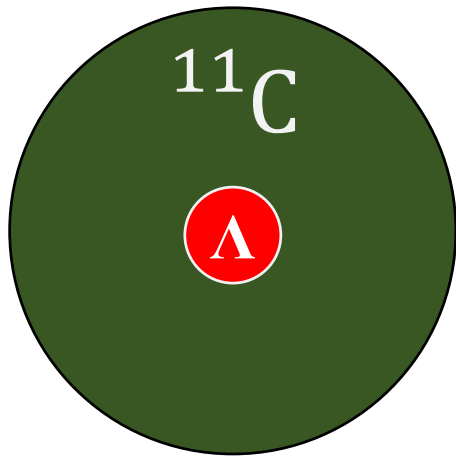
- $\delta p/p > 20\%$
- $< 10$  degrees



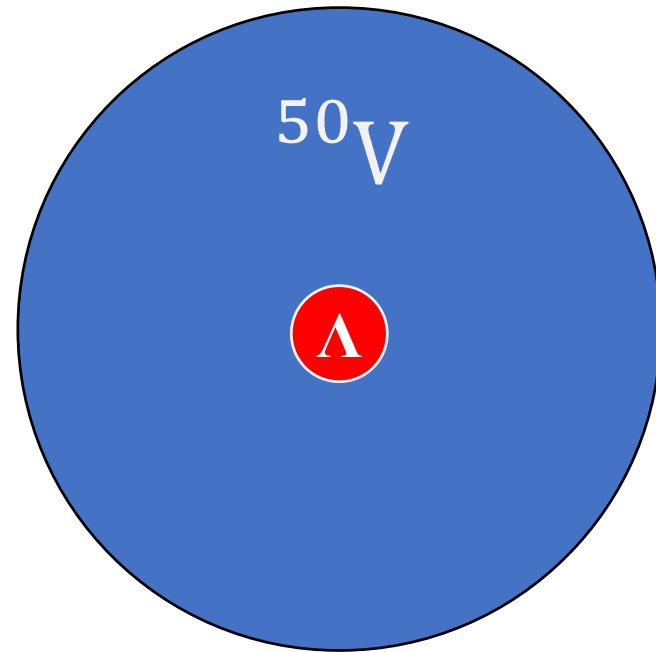


# First targets for $(\pi^+, K^+)$ experiment

FWHM  $\simeq 1$  MeV w/ S-2S



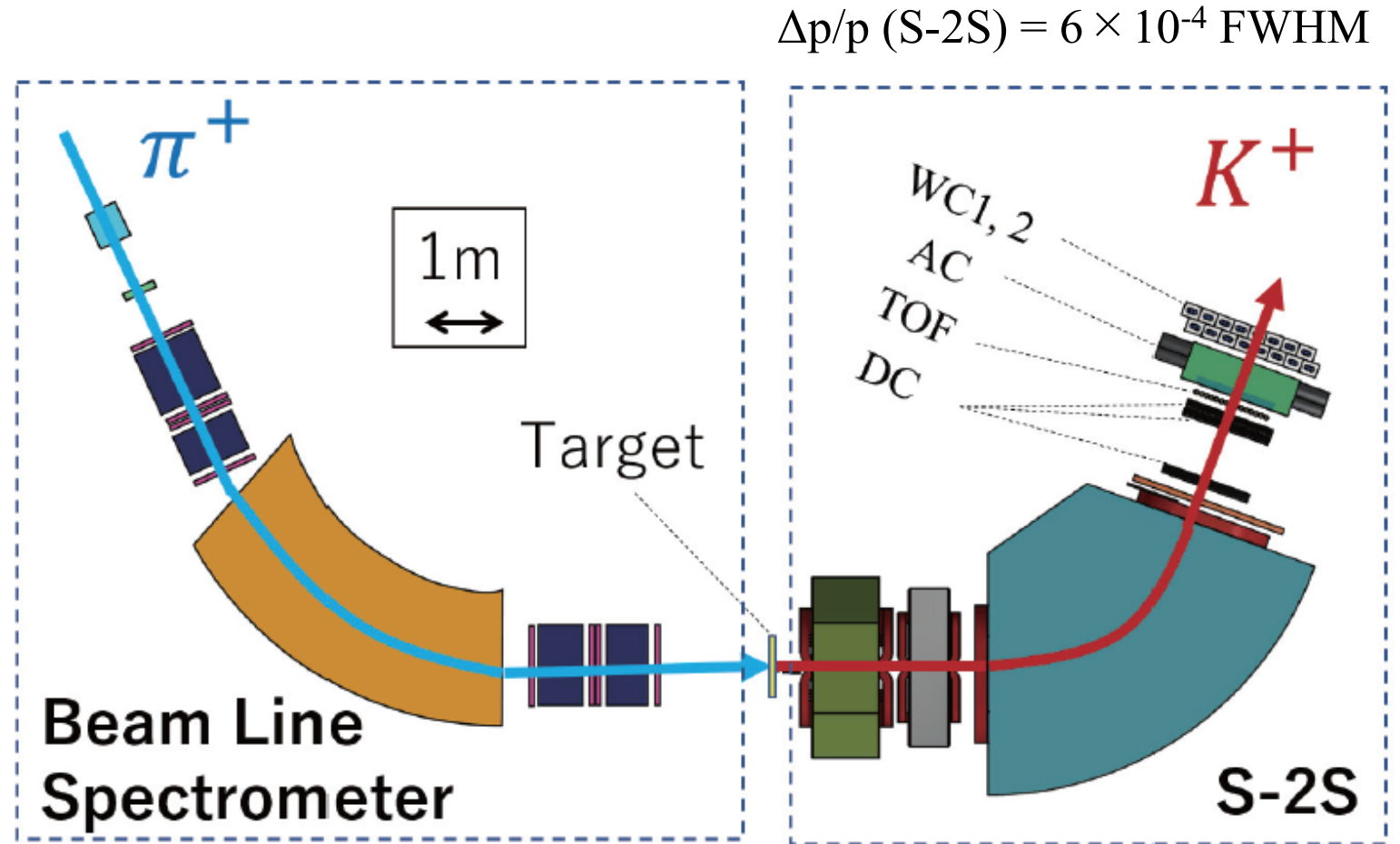
$^{12}_{\Lambda}\text{C}$



$^{51}_{\Lambda}\text{V}$

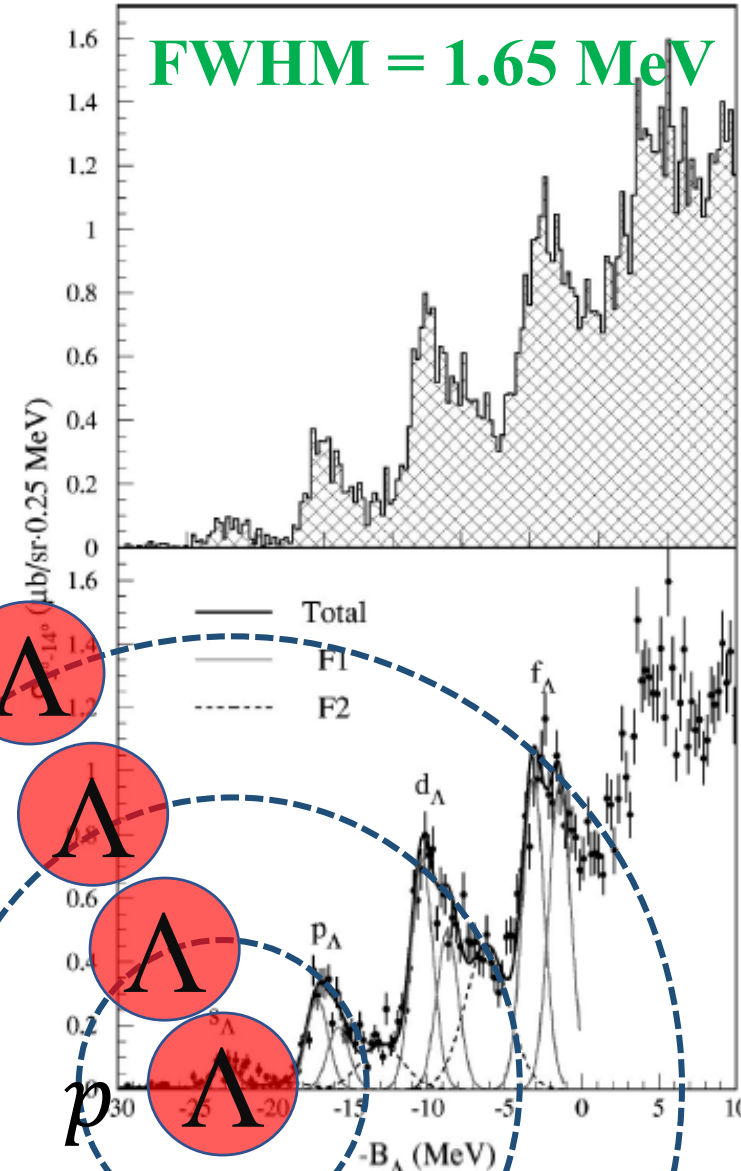
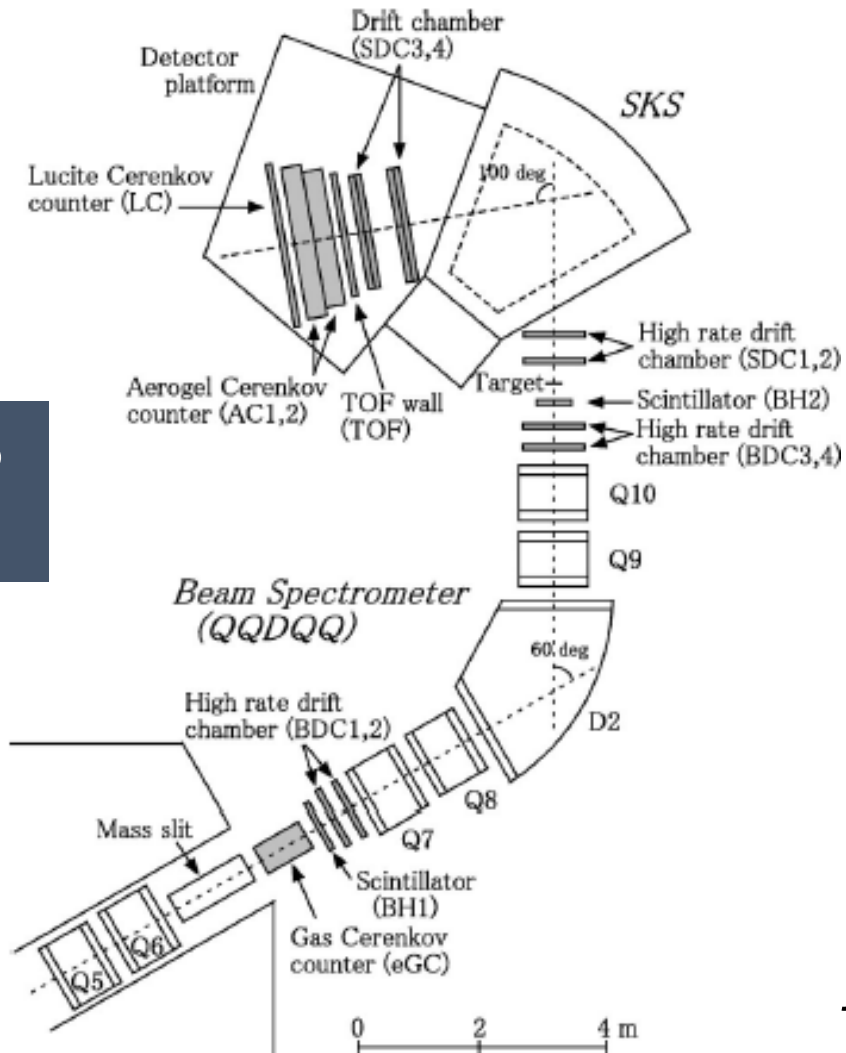
# Experimental setup

- Setup is the same as E70
- Beam polarity is opposite



# Understanding of ${}^8_9\Lambda$ , and further study

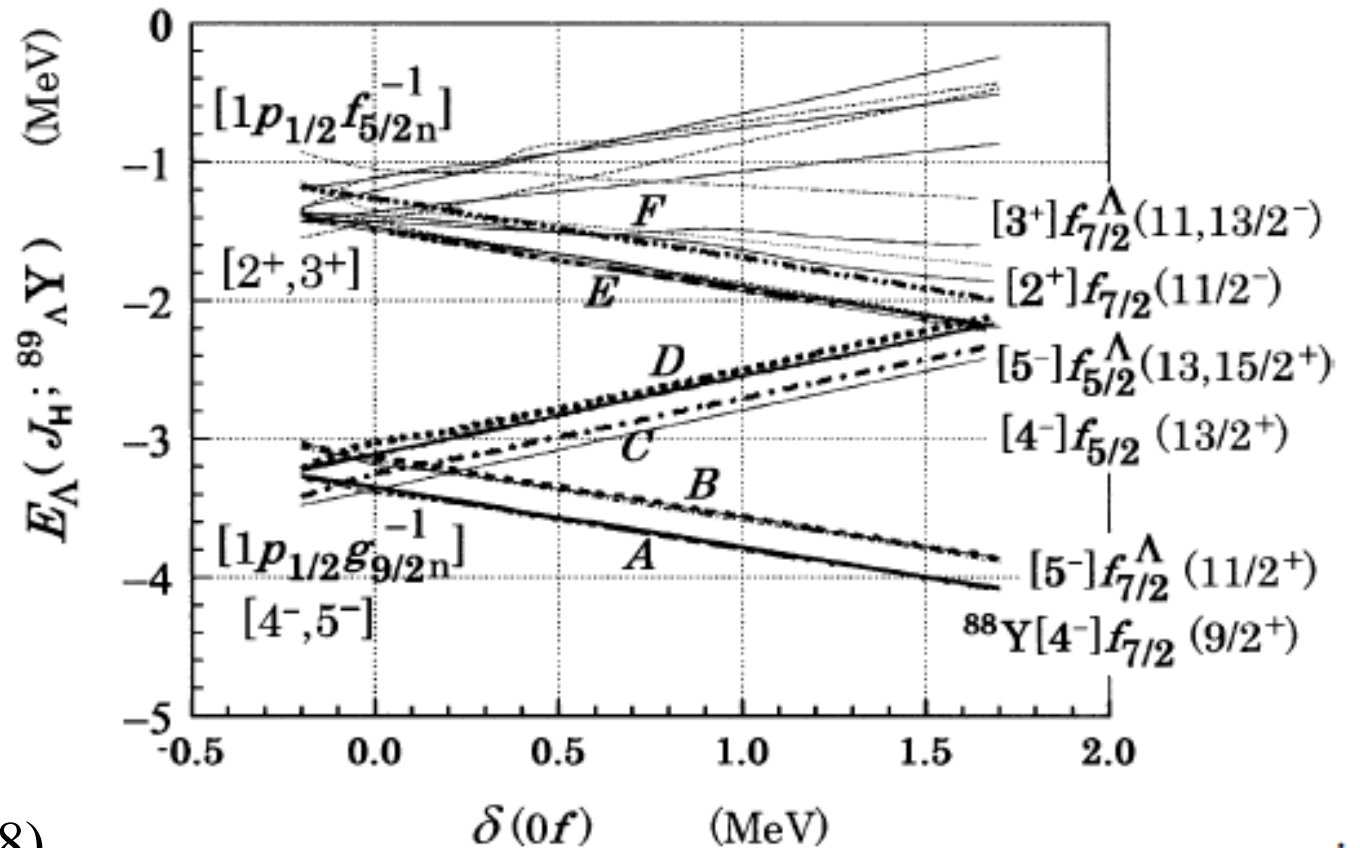
KEK-PS  
E369



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

# Test; splitting parameter

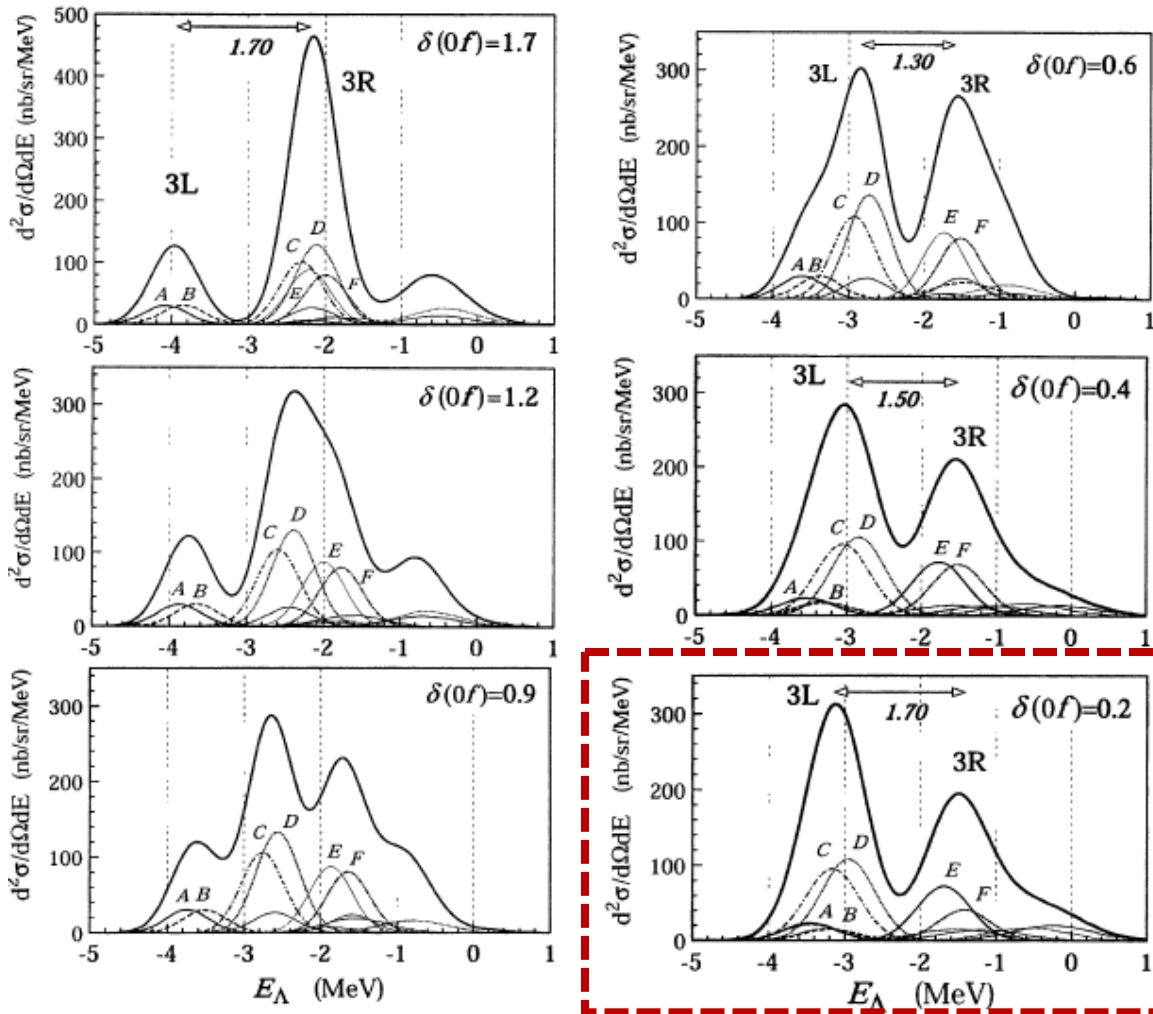
$$\delta = \epsilon(f_{5/2}^{\Lambda}) - \epsilon(f_{7/2}^{\Lambda})$$



T. Motoba et al., NPA 804, 99—115 (2008)

T. Motoba et al., PTPS 185, 197—223 (2010)

# Expected spectra with different $\delta$ ( $\Lambda$ in f-orbit)



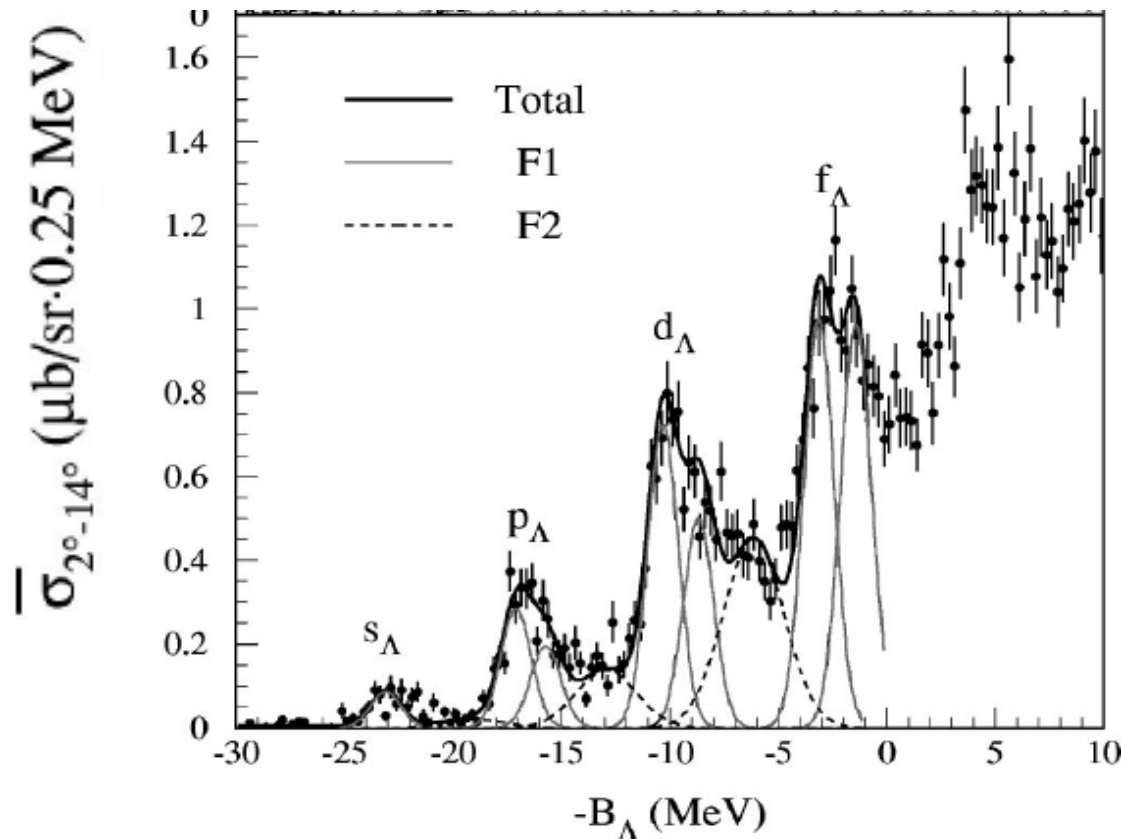
- A :  $^{88}\text{Y}(4^-) f_{7/2}^A (J_H = 9/2^+) \text{ or } [1p_{1/2p} (g_{9/2n}^{-1} f_{7/2}^A)_{J_{ph}=5-}]$ ,
- B :  $^{88}\text{Y}(5^-) f_{7/2}^A (J_H = 11/2^+) \text{ or } [1p_{1/2p} (g_{9/2n}^{-1} f_{7/2}^A)_{J_{ph}=5-}]$ ,
- C :  $^{88}\text{Y}(4^-) f_{5/2}^A (J_H = 13/2^+) \text{ or } [1p_{1/2p} (g_{9/2n}^{-1} f_{5/2}^A)_{J_{ph}=7-}]$ ,
- D :  $^{88}\text{Y}(5^-) f_{5/2}^A (J_H = 15/2^+, 13/2^+) \text{ or } [1p_{1/2p} (g_{9/2n}^{-1} f_{5/2}^A)_{J_{ph}=7-}]$ ,
- E :  $^{88}\text{Y}(2^+) f_{7/2}^A (J_H = 11/2^-) \text{ or } [1p_{1/2p} (f_{5/2n}^{-1} f_{7/2}^A)_{J_{ph}=6+}]$ ,
- F :  $^{88}\text{Y}(3^+) f_{7/2}^A (J_H = 11/2^-, 13/2^-) \text{ or } [1p_{1/2p} (f_{5/2n}^{-1} f_{7/2}^A)_{J_{ph}=6+}]$ .

Small LS force seems to be better consistency with  $^{89}_{\Lambda}\text{Y}$  data

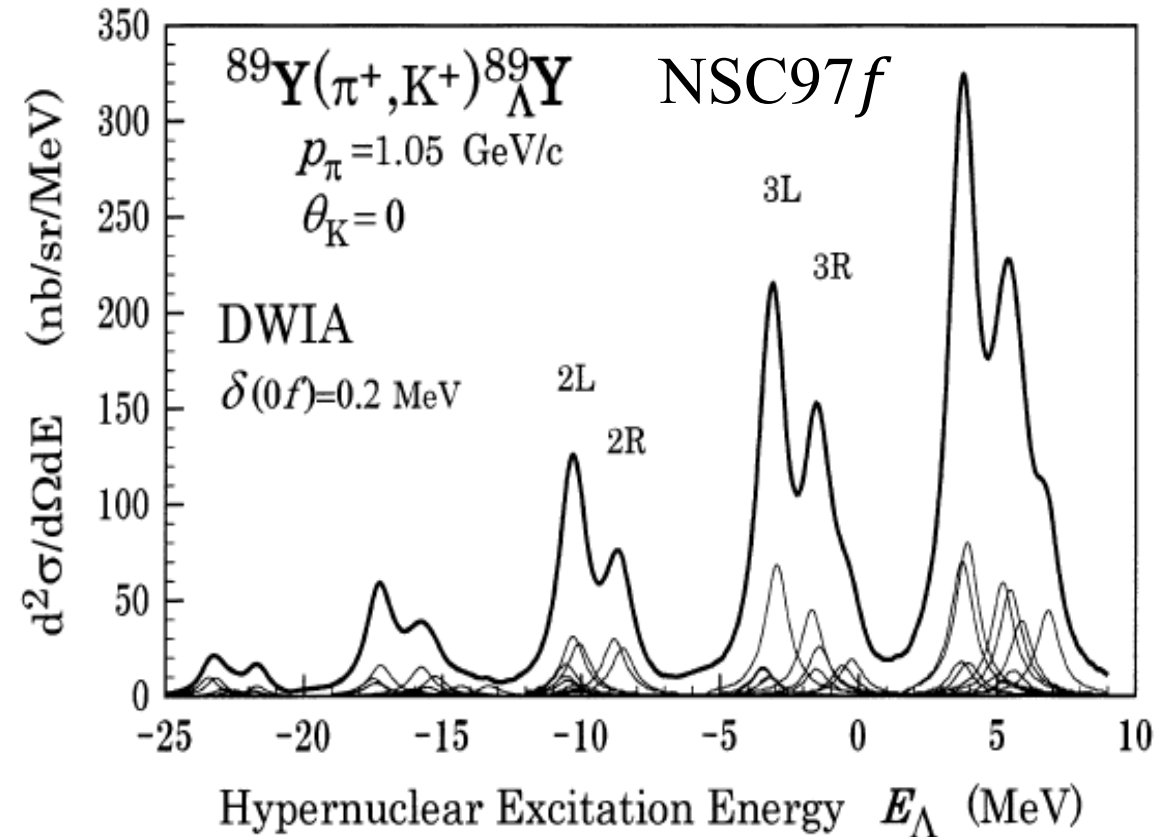
← Consistent with results of the  $\gamma$  ray measurements as well

# Experiment vs. calculation (KEK PS E)

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

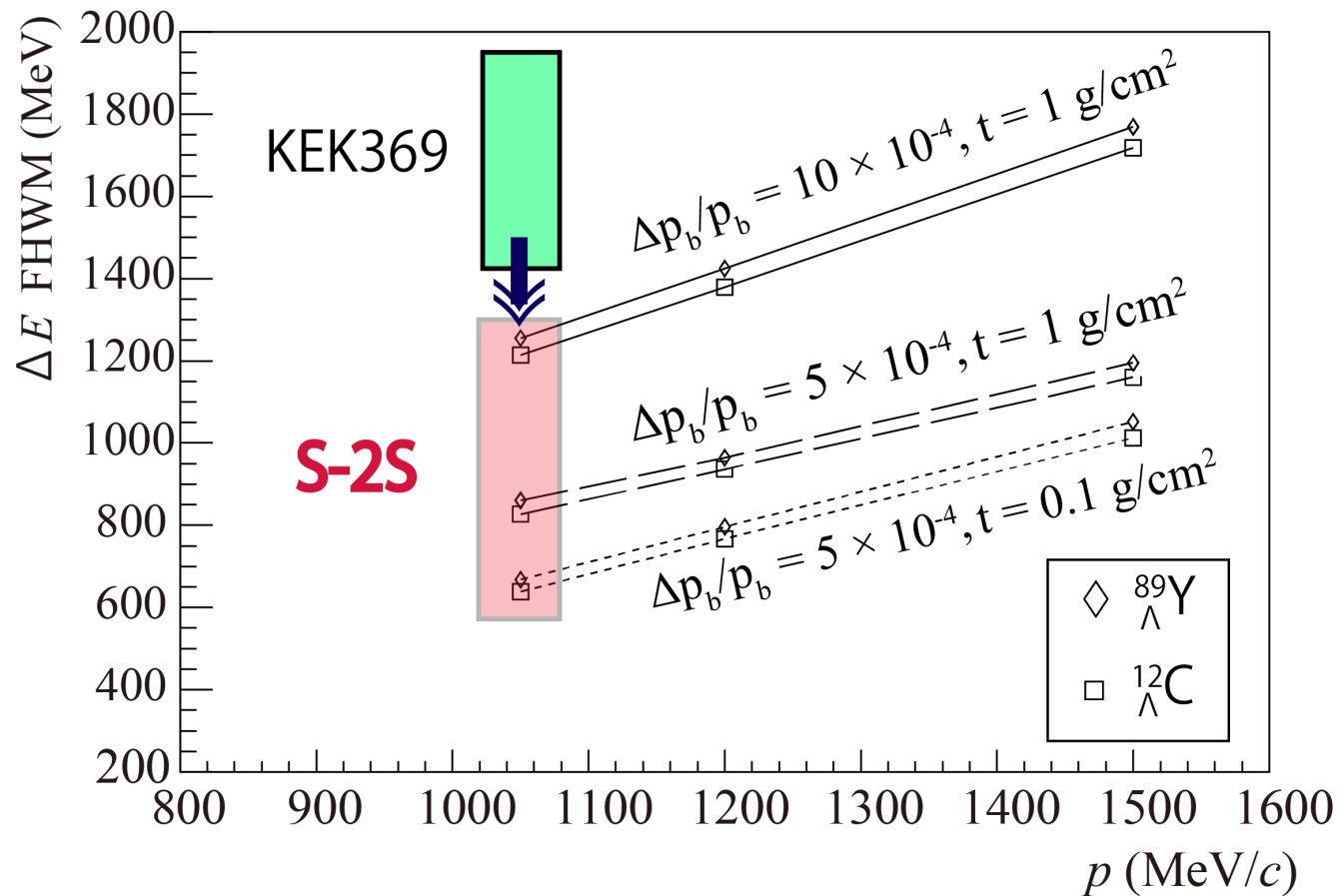


T. Motoba et al., NPA 804, 99—115 (2008)  
 T. Motoba et al., PTPS 185, 197—223 (2010)



Did we satisfied?  $\rightarrow$  We need further investigation (e.g. F2)

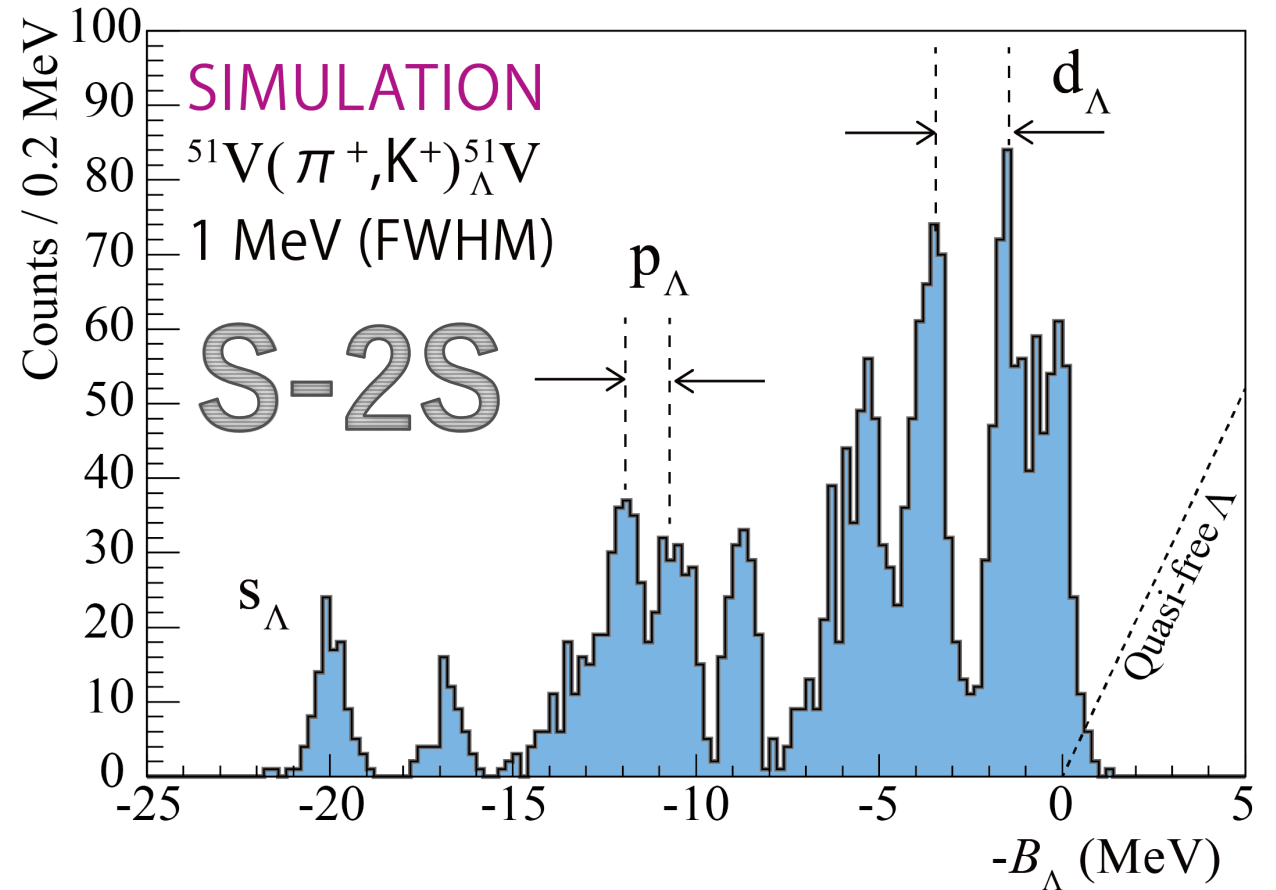
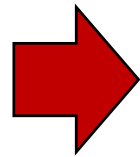
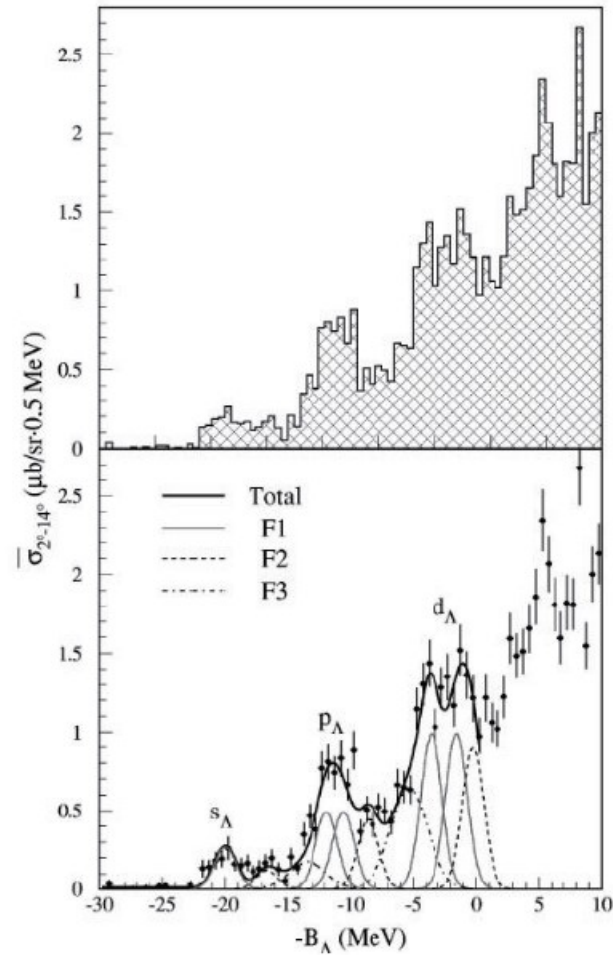
# Expected energy resolution



1 MeV FWHM

# Expected spectrum

will be proposed in the next J-PARC PAC (Jan 2022)



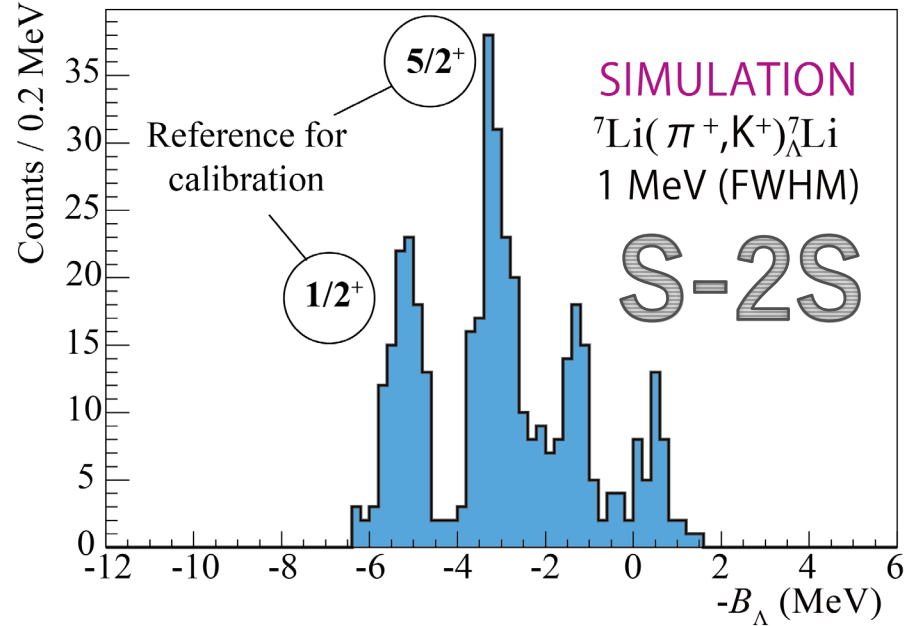
H. Hotchi et al., PRC 64, 044302 (2001)

5M pion/spill, 5.2 sec cycle, 1 g/cm<sup>2</sup>, 20 days



# Absolute energy calibration

5M pion/spill, 5.2 sec cycle, 1 g/cm<sup>2</sup>, 1 day



5M pion/spill, 5.2 sec cycle, 1 g/cm<sup>2</sup>, 2 days

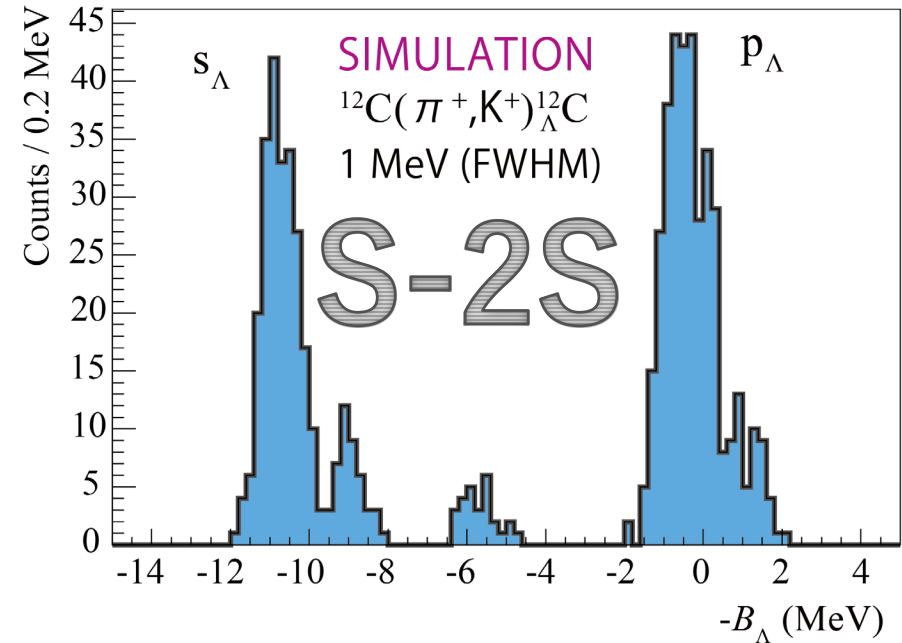


TABLE VIII. Reference energies ( $B_{\Lambda}^{\text{ref.}}$ ) for the present experiment. Expected statistical errors on the binding-energy measurement ( $|\Delta B_{\Lambda}^{\text{stat.}}|$ ) in the present experiment are shown in the last column.

Hypernucleus	$J^{\pi}$	$B_{\Lambda}^{\text{ref.}}$ (/MeV)	Remarks	$ \Delta B_{\Lambda}^{\text{stat.}} $ (/MeV)
${}^7_{\Lambda}\text{Li}$	$1/2^+$ (g.s.)	$5.58 \pm 0.03$	Ref. [8]	0.04
	$5/2^+$	$3.53 \pm 0.03$	Refs. [6, 8]	0.03
${}^{12}_{\Lambda}\text{C}$	$1^-$ (g.s.)	$11.45 \pm 0.13$	weighted average of Refs. [4, 9]	0.03

# Plan up to physics runs (J-PARC E70)

## 2022

Jan—Mar

- S-2S will be moved to J-PARC
- S-2S installation
- Excitation test

Apr—Oct

- Detectors' installation / check

Nov—Dec

- Commissioning with beam  
( $\sim$  two weeks of beamtime)

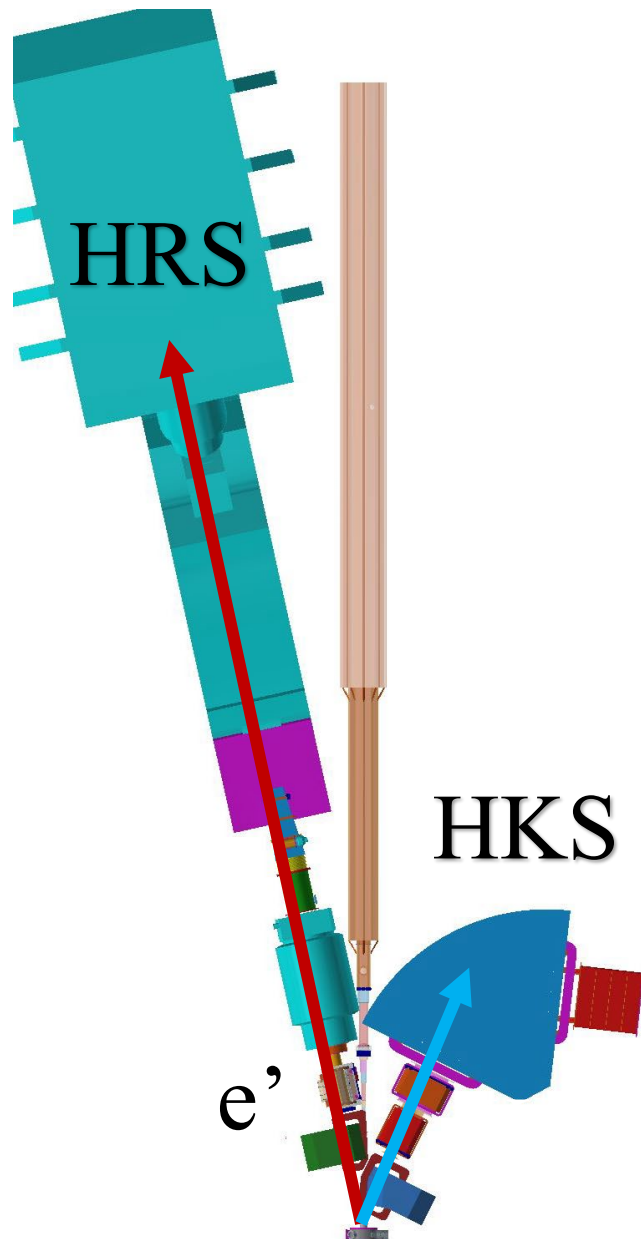
## 2023

(about 1—2 months for analysis)

Jan~Mar—

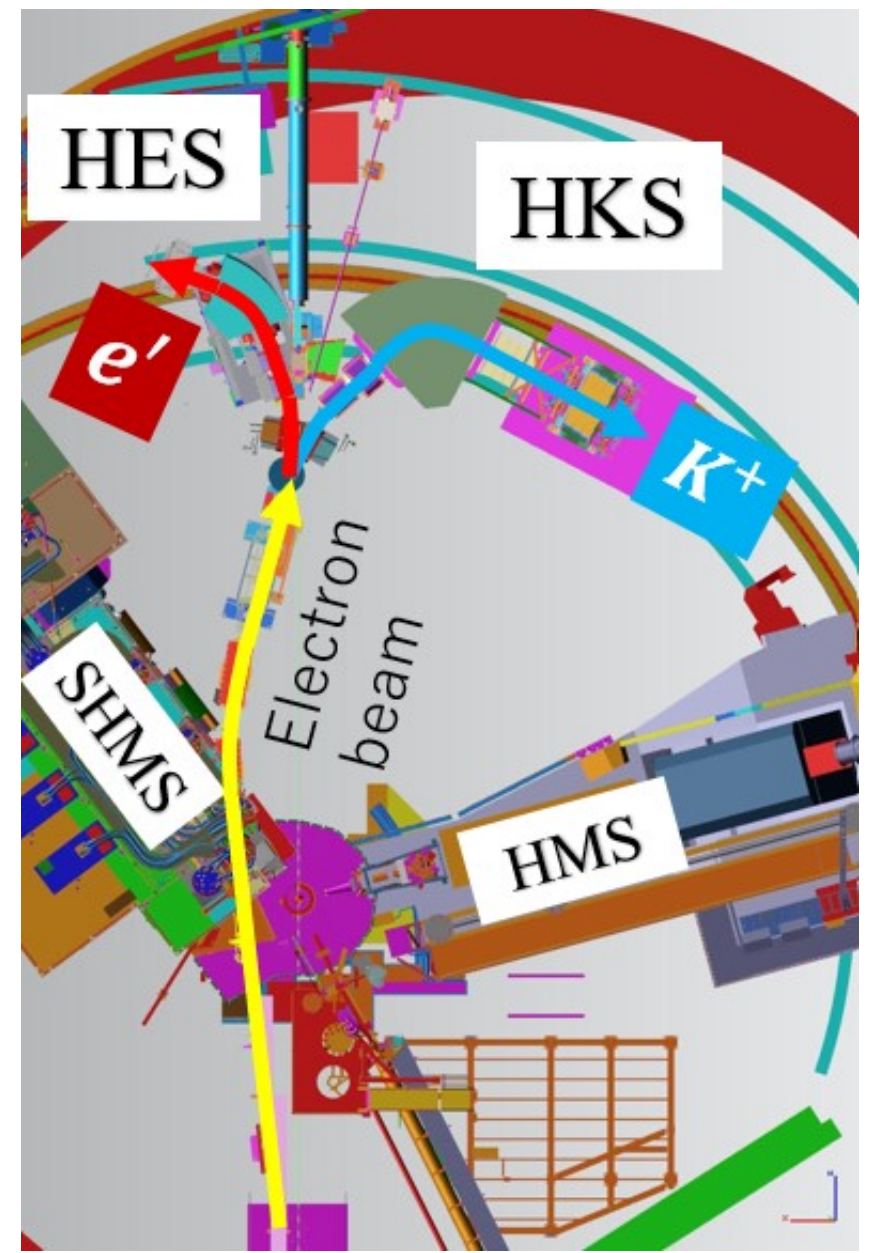
- Commissioning runs  
(a few days of beamtime)
- **Physics runs**

Experiment	Target (thickness [/(g/cm <sup>2</sup> )])	Contents	( $p_{\text{Beam}}^{\text{cent.}}$ , $p_{\text{S-2S}}^{\text{cent.}}$ ) [/(MeV/c)]	beam time (/hours)
New	<sup>12</sup> C (0, 3)	Beam through (BT)	~ A: (1050, 740)	12
New	<sup>12</sup> C (3)	<sup>12</sup> C( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>12</sup> C	A	24
New	<sup>12</sup> C (1)	<sup>12</sup> C( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>12</sup> C	A	48
New	<sup>7</sup> Li (1)	<sup>7</sup> Li( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>7</sup> Li	A	24
New	<sup>51</sup> V (1)	<sup>51</sup> V( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>51</sup> V	A	160
New	<sup>12</sup> C (3)	<sup>12</sup> C( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>12</sup> C	B: (1300, 1000)	24
E70	<sup>12</sup> C (3)	<sup>12</sup> C( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>12</sup> C	C: (1640, 1370)	80
E70	<sup>12</sup> C (0, 3)	BT	~ D: (1800, 1370)	12
E70	CH <sub>2</sub> (3)	$p(K^-, K^+)\Xi^-$	D	24
E70	CH <sub>2</sub> (1)	$p(K^-, K^+)\Xi^-$	D	24
E70	AFT (9)	AFT commissioning	D	48
E70	AFT (9)	<sup>12</sup> C( $K^-, K^+$ ) <sub><math>\Xi</math></sub> <sup>12</sup> Be	D	48
Analysis				(> $\approx$ 1 month)
E70	<sup>12</sup> C (0, 3)	BT + detector commis.	~ D	48
E70	AFT (9)	<sup>12</sup> C( $K^-, K^+$ ) <sub><math>\Xi</math></sub> <sup>12</sup> Be	D	$\approx$ 576
New	<sup>12</sup> C (0, 3)	BT + detector commis.	~ A	12
New	<sup>51</sup> V (1)	<sup>51</sup> V( $\pi^+$ , $K^+$ ) <sub><math>\Lambda</math></sub> <sup>51</sup> V	A	320



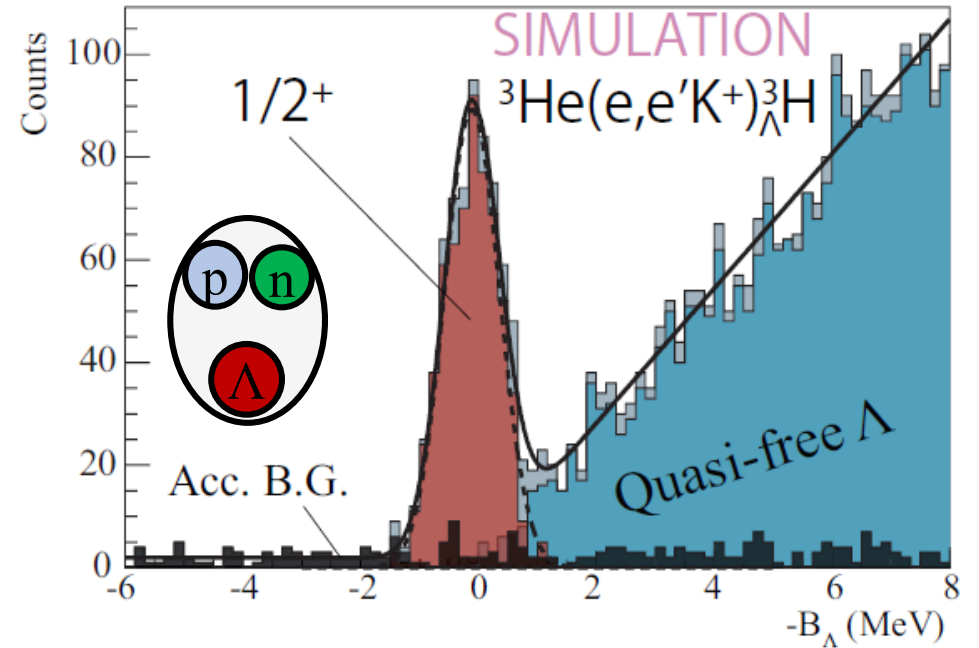
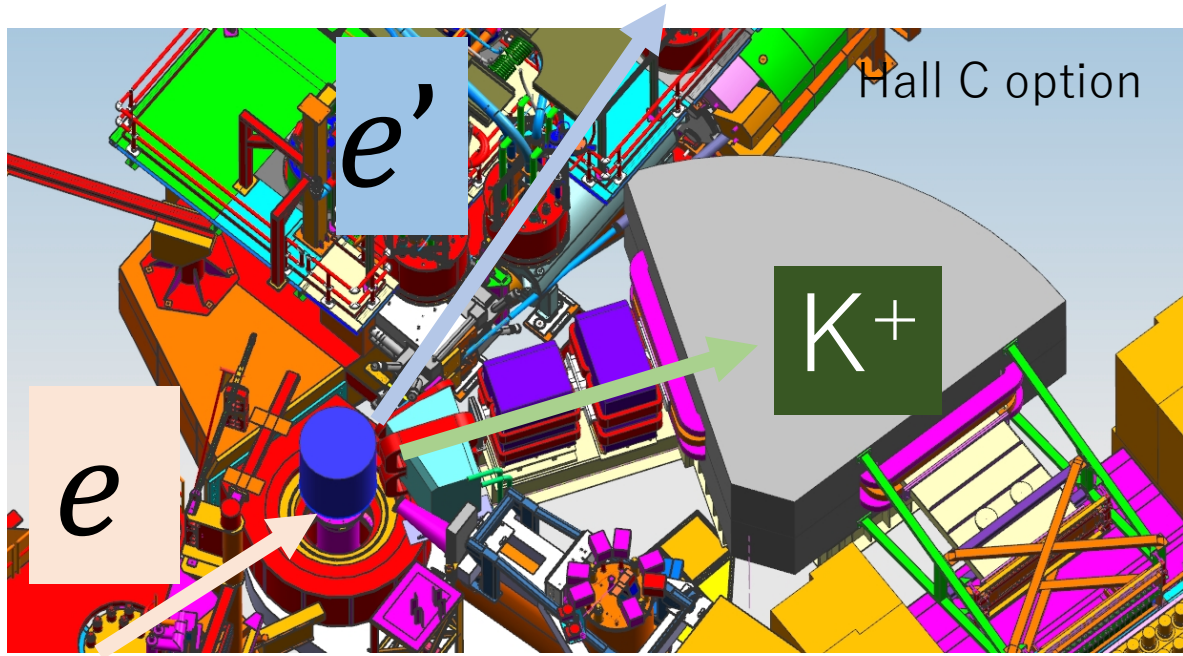
Hall A

Future  
experiment  
at JLab



Hall C

# Future programs being prepared



- ${}^3, {}^4_{\Lambda}\text{H}$  (E12-19-002)  $\rightarrow$  lifetime puzzle, CSB,  $3/2^+$
- ${}^{40, 48}_{\Lambda}\text{K}$  (E12-15-008)  $\rightarrow$  Isospin dependence
- ${}^{208}_{\Lambda}\text{Tl}$  (E12-20-013)  $\rightarrow$  NN  $\Lambda$  interaction

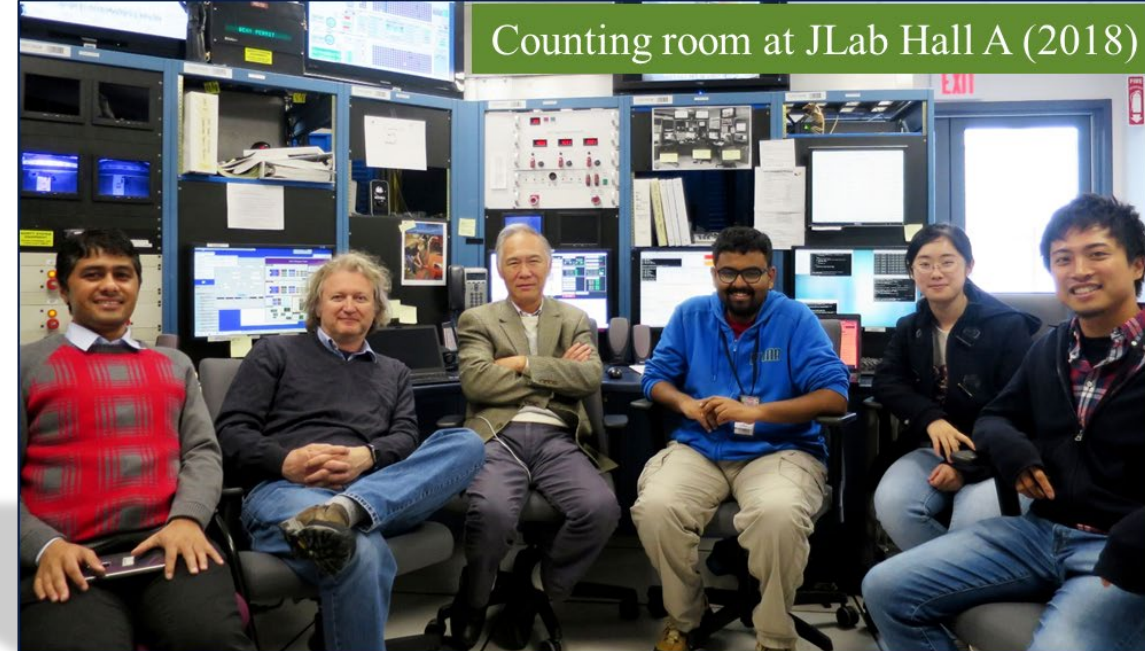
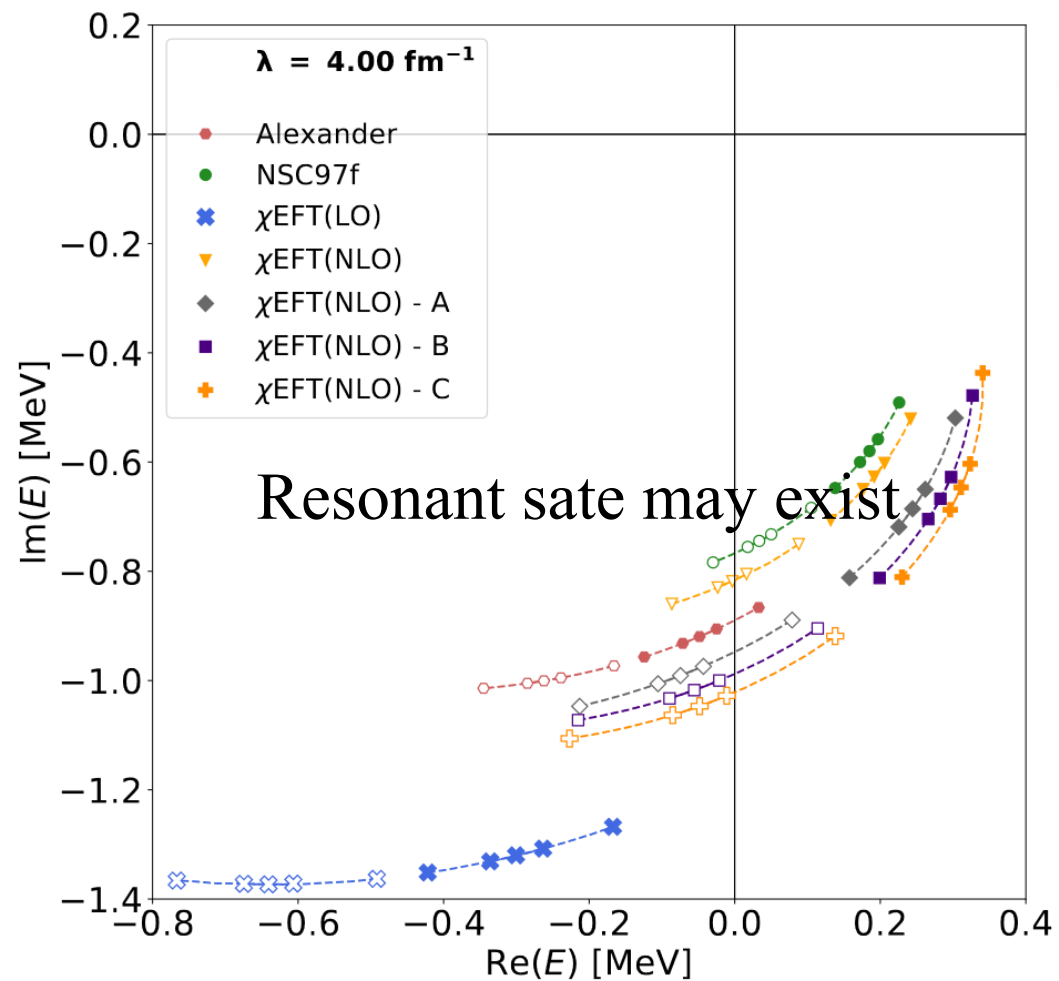
**Very high accuracy**

$$\Delta B_{\Lambda}^{\text{total}} = \pm 60 \text{ keV}$$

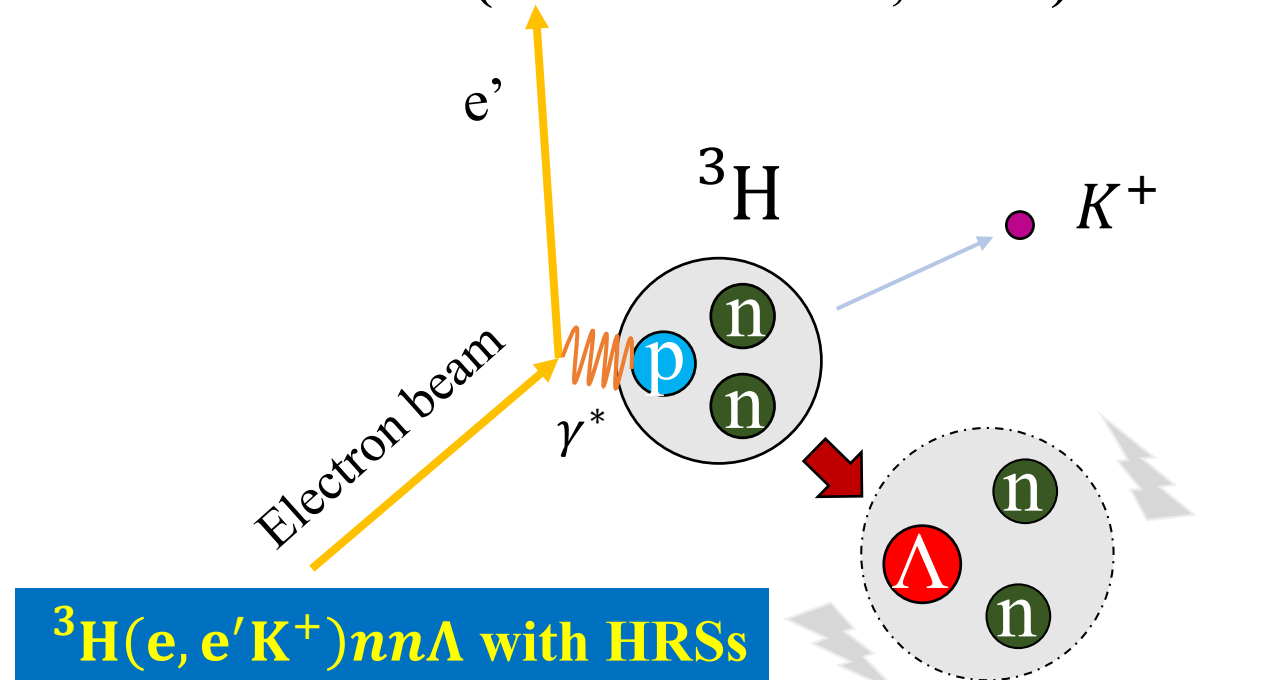
$\rightarrow$  Aim to carry out in 2024~

# nn $\Lambda$ search

M. Schafer et al., arXiv:2108.13900v1 [nucl-th]  
31 Aug 2021

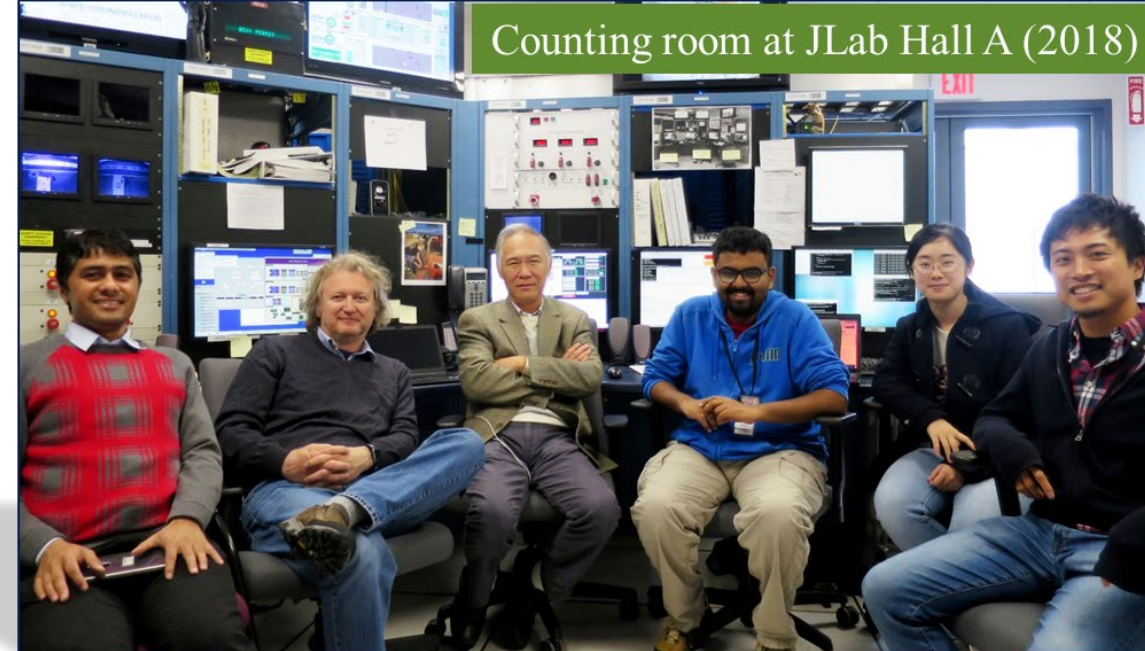
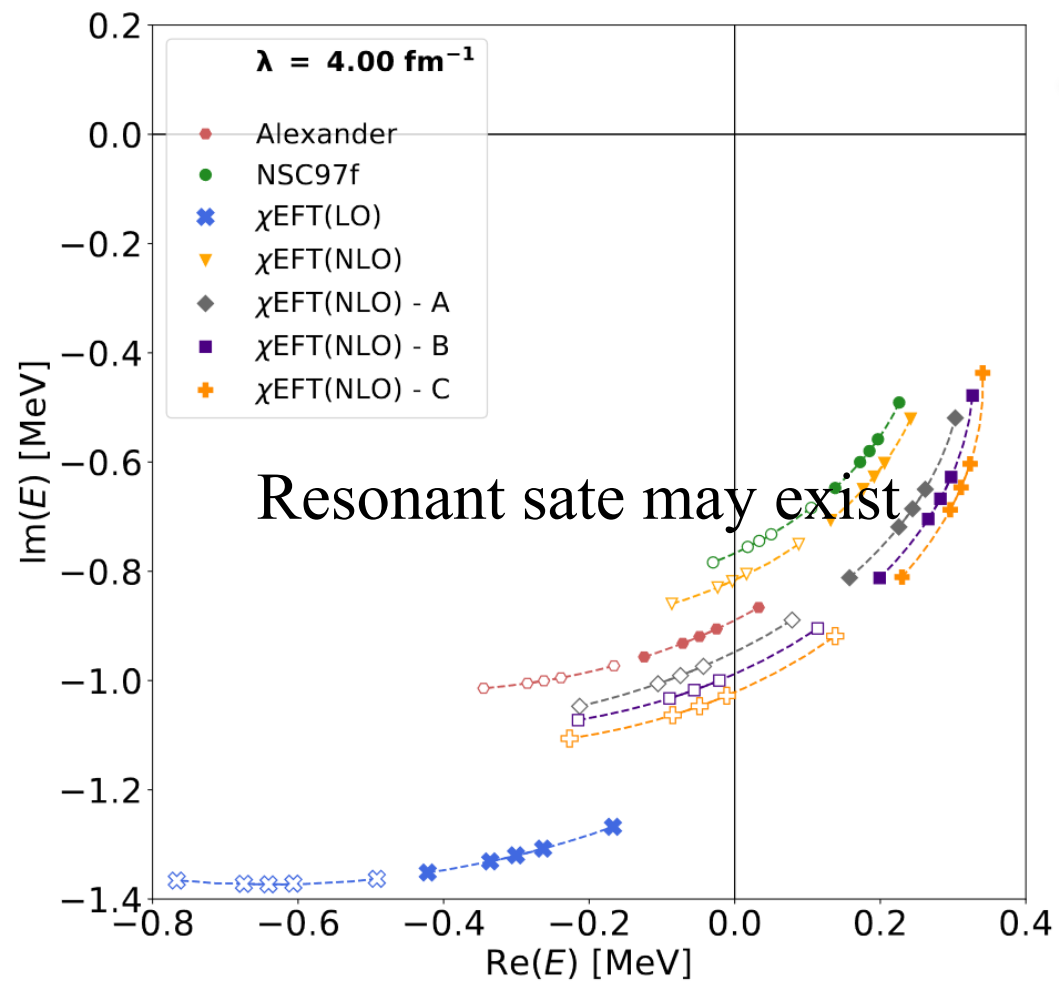


E12-17-003 (Oct 30—Nov 25, 2018)

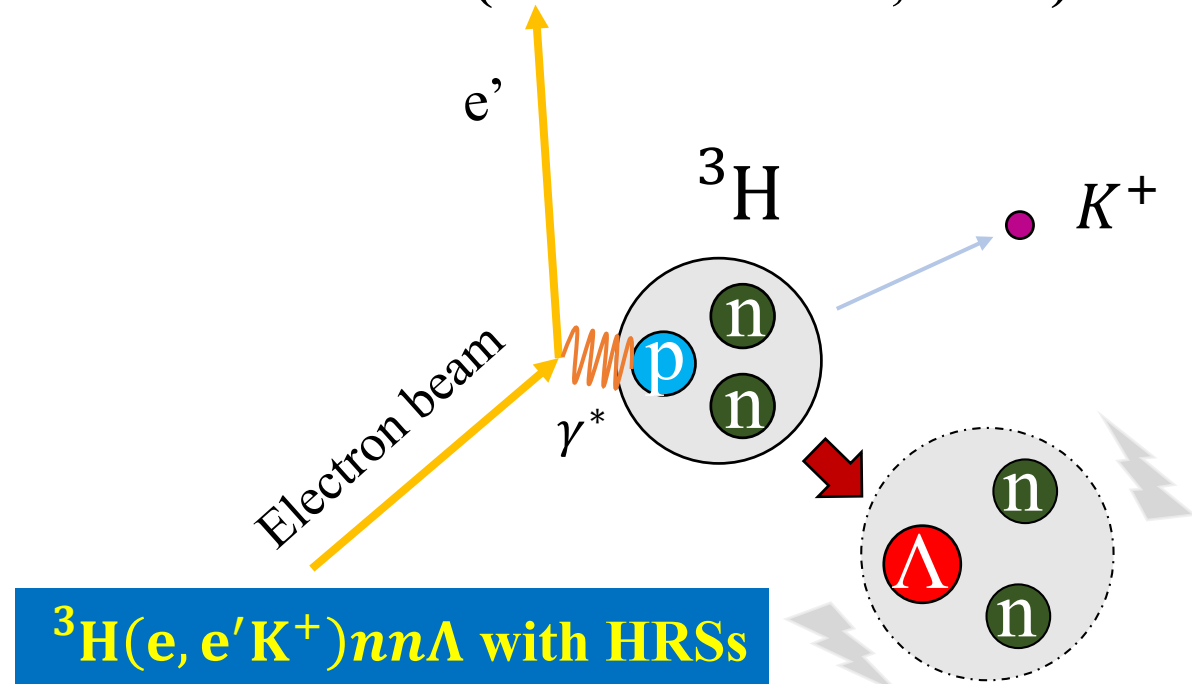


# nn $\Lambda$ search

M. Schafer et al., arXiv:2108.13900v1 [nucl-th]  
31 Aug 2021



E12-17-003 (Oct 30—Nov 25, 2018)



ACCEPTED MANUSCRIPT

# The cross-section measurement for the ${}^3\text{H}(e, e'K^+)nn\Lambda$ reaction

K N Suzuki , T Gogami , B Pandey, K Itabashi, S Nagao, K Okuyama, S N Nakamura, L Tang, D Abrams, T Akiyama ... [Show more](#)

*Progress of Theoretical and Experimental Physics*, ptab158, <https://doi.org/10.1093/ptep/ptab158>

**Published:** 06 December 2021



# Result ( $nn\Lambda$ )

[PTEP \(2021\)](#)

arXiv:2110.09104 [nucl-ex]

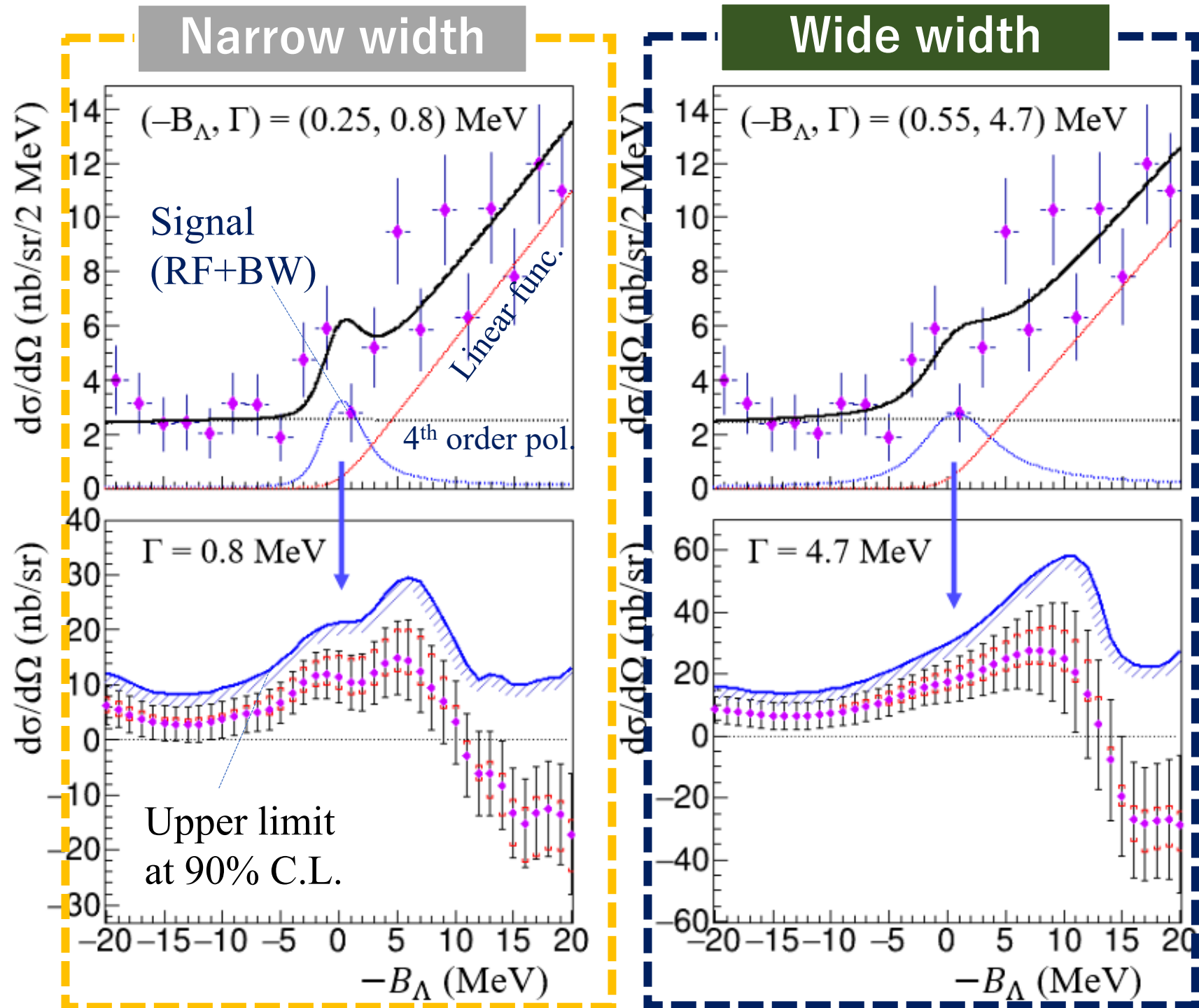
**Test case1:** narrow width  $\Gamma = 0.8$  MeV

K.M.Kamada et al.,  
EPJ Conf. 113, 07004 (2016)

**Test case2:** wide width  $\Gamma = 4.7$  MeV

V.B. Belyaev et al., NPA 803, 210 (2008)

Unbinned maximum  
likelihood fitting  
→ Cross section



# Summary

## 1. S-2S @J-PARC

- ${}^5_1\Lambda\text{V}$  (+  ${}^7_1\Lambda\text{Li}$ ,  ${}^{12}_1\Lambda\text{C}$ )
  - Feasibility of 1 MeV FWHM spectroscopy of  $\Lambda$  hypernuclei
  - Absolute  $\rightarrow |\Delta B_\Lambda| \sim 100$  keV
  - S-2S commissioning

## 2. HKS @JLab

- $nn\Lambda$  search (2018)  $\rightarrow$  Cross section ([PTEP 2021](#)), peak search, FSI
- Future projects (2024 $\sim$ )
  - ${}^3,4_1\Lambda\text{H}$  (E12-19-002)  $\rightarrow$  lifetime puzzle and  $3/2^+$  existence for hypertriton, CSB
  - ${}^{40,48}_1\Lambda\text{K}$  (E12-15-008)  $\rightarrow$  Isospin dependence
  - ${}^{208}_1\Lambda\text{Tl}$  (E12-20-013)  $\rightarrow$  NN  $\Lambda$  interaction