Study of the charge symmetry breaking effect in A=4 Λ-hypernuclei via gamma-ray spectroscopy

Mifuyu Ukai

KEK/J-PARC Hadron

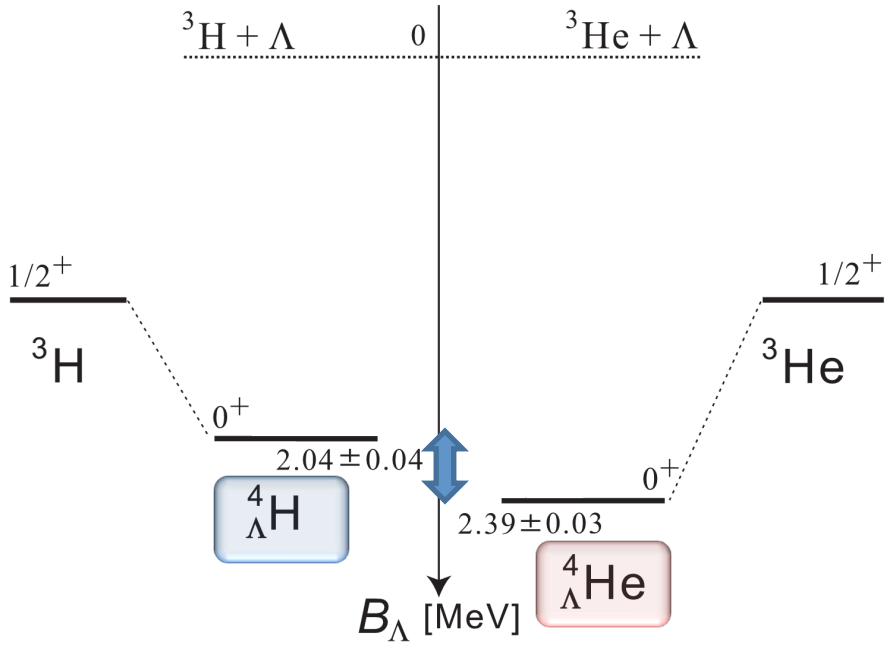
for the E13/E63 collaboration

Contents

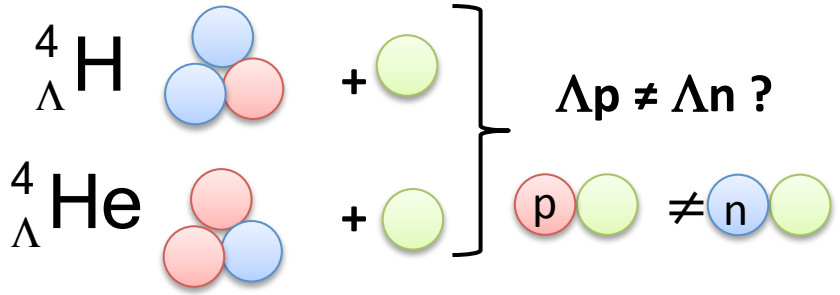
Charge symmetry breaking (CSB) in ΛN-interaction

$\Delta B_\Lambda (0^+) = 0.35$ MeV

Large CSB in ΛN-interaction ?



0^+ state =>350 keV difference from emulsion data (g.s. 0+)



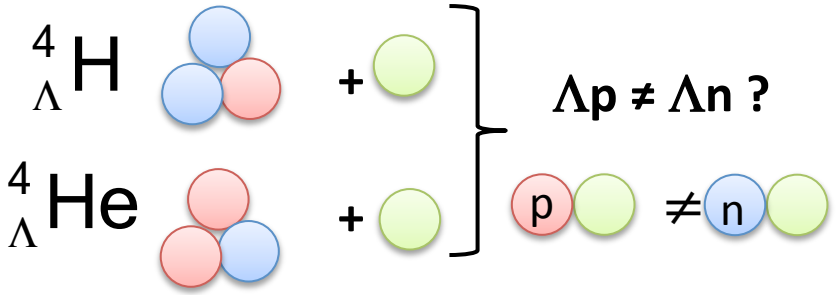
A. Nogga, H. Kamada, and W. Gloockle, Phys. Rev. Lett. 88, 172501 (2002)

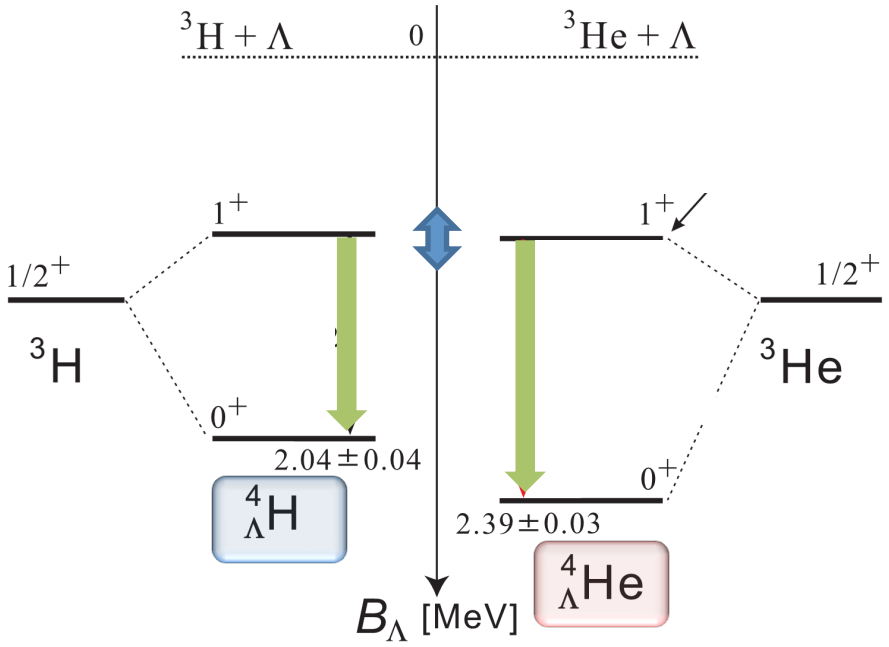
Considering
- **Coulomb force**
- **2 body ΛN-ΣN coupling**
  (⇒ 3 body ΛN-ΣN mixing)

Previously, many theoretical studies, but could not reproduce data

Re-examination of existing data were long awaited

Charge symmetry breaking (CSB) in ΛN-interaction





Differencies of
(1⁺, 0⁺) spacing energy / 1⁺ binding energy
= > 1⁺ -> 0⁺ gamma-ray energy + emulsion data

A. Nogga, H. Kamada, and W. Gloockle, Phys. Rev. Lett. 88, 172501 (2002)

Considering
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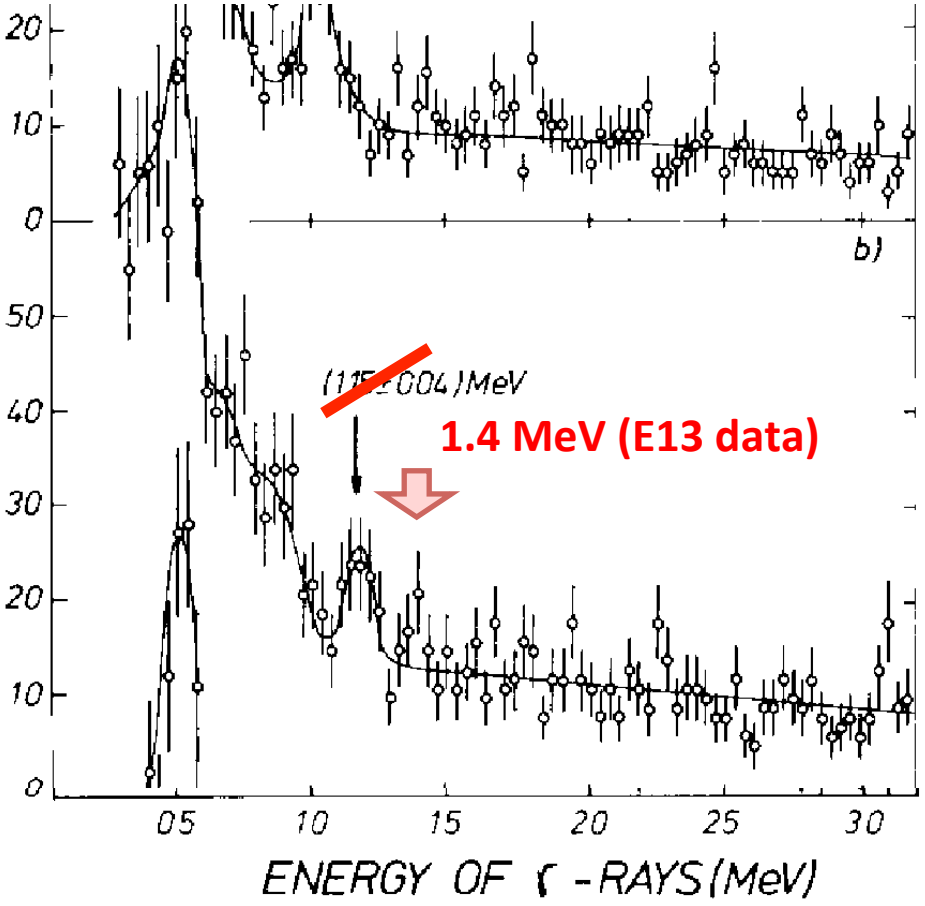
Previous γ-ray spectroscopy for ${}^{4}_{\Lambda}\mathrm{He}(1^{+}\rightarrow 0^{+})$



M. Bedjidian et al., Phys. Lett. B 83, 252 (1979).

reported value : ~~1.15~~ (0.04) MeV

${}^{4}_{\Lambda}\mathrm{He}(1^{+})$ production
as **hyperfragment**
via stopped K^{-} on Li target

By NaI counters

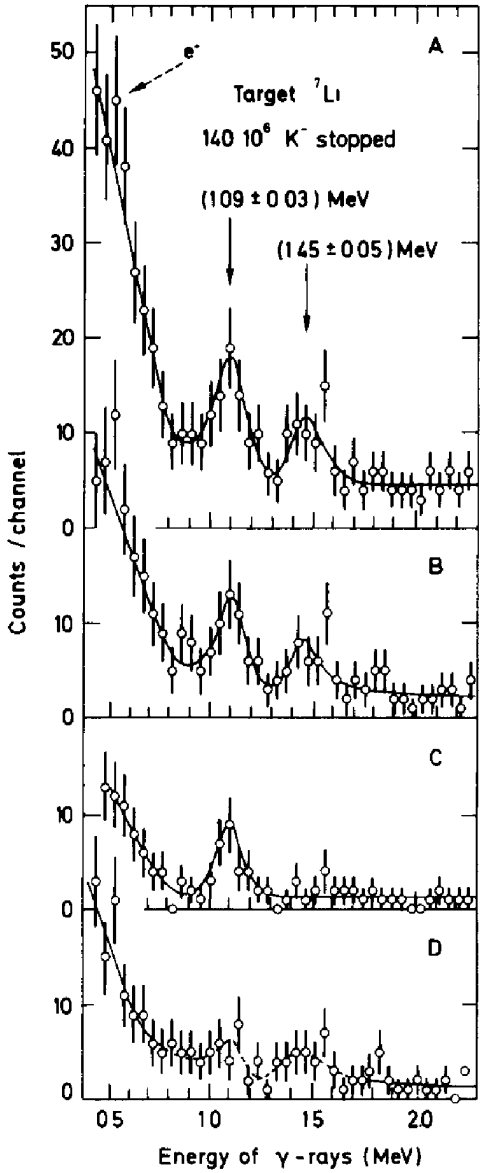
160 keV(FWHM) resolution
180 keV w/ Doppler broad

Precise measurement by Ge detector
4 keV(FWHM) resolution
17 keV(FWHM) w/ Doppler shift correction

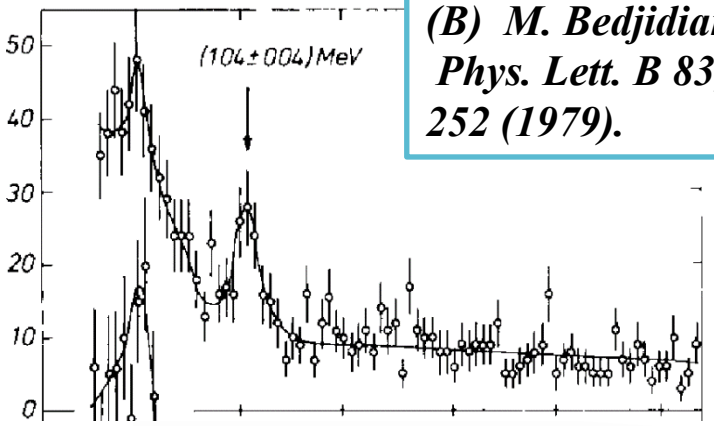
J-PARC E13 (2015)

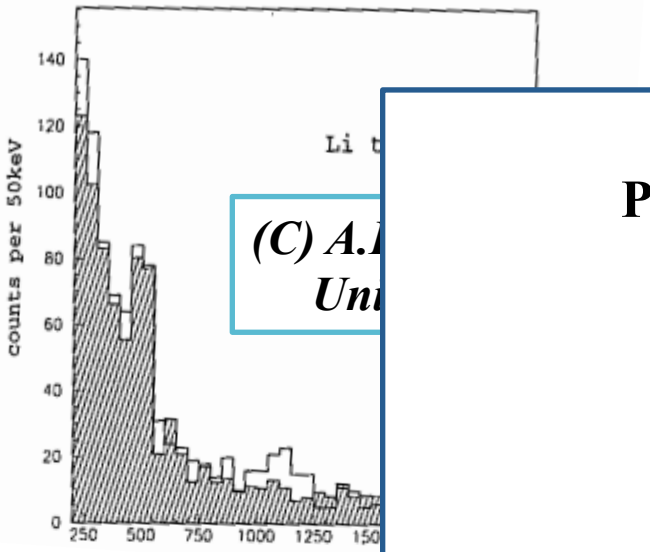
Previous γ-ray spectroscopy for $^{4}_{\Lambda}H(1^{+}\rightarrow 0^{+})$

(A) M. Bedjidian et al. Phys. Lett. B 62, 467 (1976).



(B) M. Bedjidian et al. Phys. Lett. B 83, 252 (1979).





(C) A.I
Uni

$^{4}_{\Lambda}H(1^{+})$ production
as **hyperfragment**
via stopped K^{-} on Li target

By NaI counters

70~ 160 keV(FWHM) resolution
160 ~ 180 keV(FWHM) w/ Doppler broad

Precise measurement by Ge detector
4 keV(FWHM) resolution
42 keV (FWHM)w/ Doppler broad

J-PARC E63 (~2018)

Large Doppler-broadening of γ peak
~ 160 keV (FWHM) (with 7%NaI resolution;kawachi)

(A) (B) (C)

New data
The J-PARC E13 experiment

$^{4}_{\Lambda}\mathrm{He}(1^{+}\rightarrow 0^{+})$ measurement

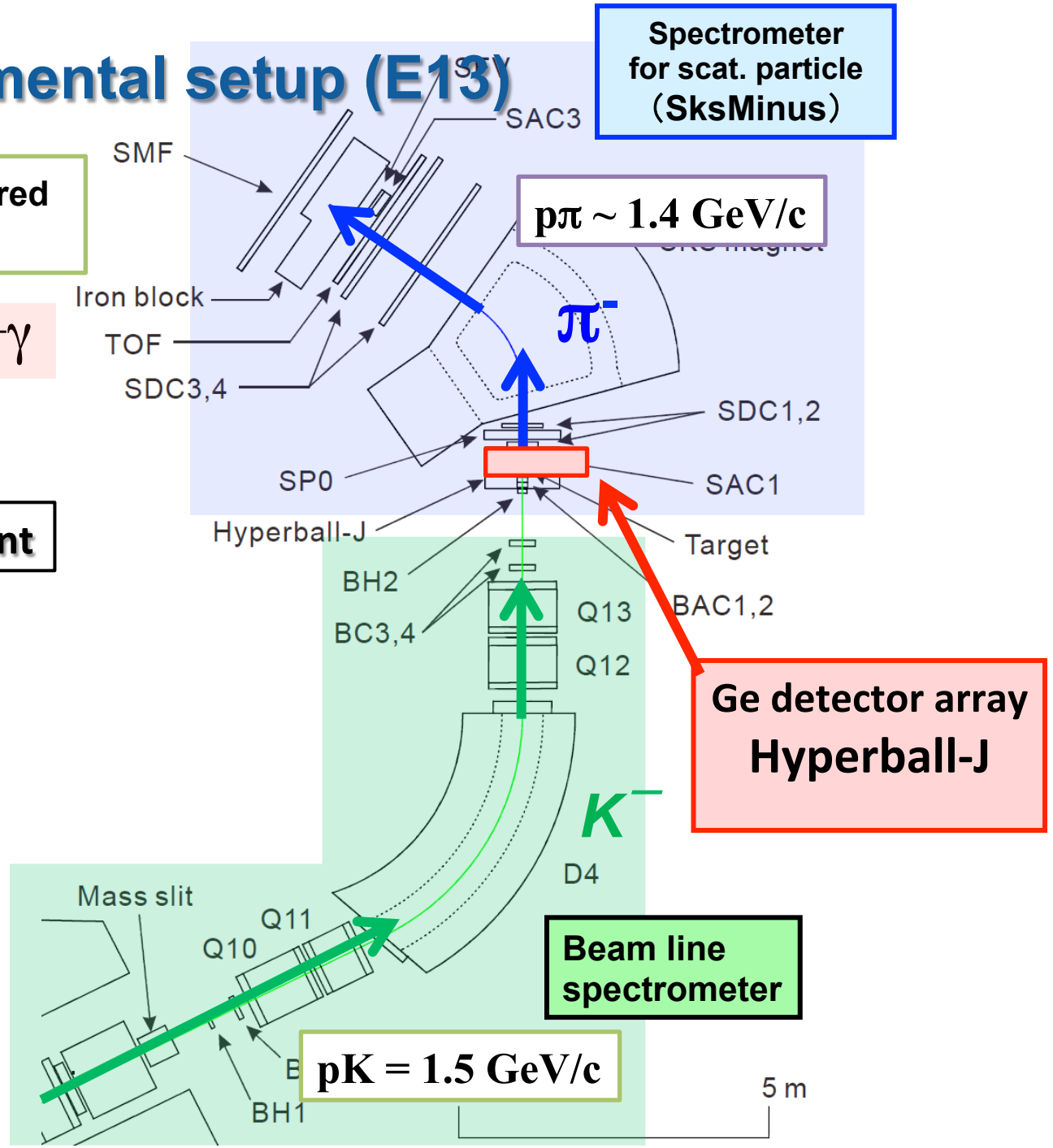
K1.8 experimental setup (E13)

Use high intensity K- beam delivered to J-PARC K1.8 beam line

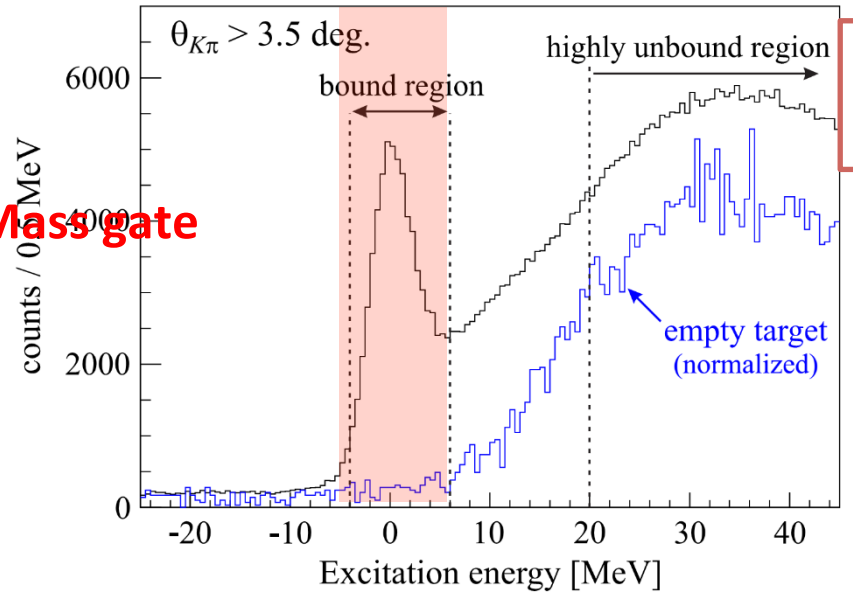
$^{4}\mathrm{He}(K^{-},\pi^{-})^{4}_{\Lambda}\mathrm{He}^{*} \rightarrow {}^{4}_{\Lambda}\mathrm{He}+\gamma$

reaction-γ coincidence experiment

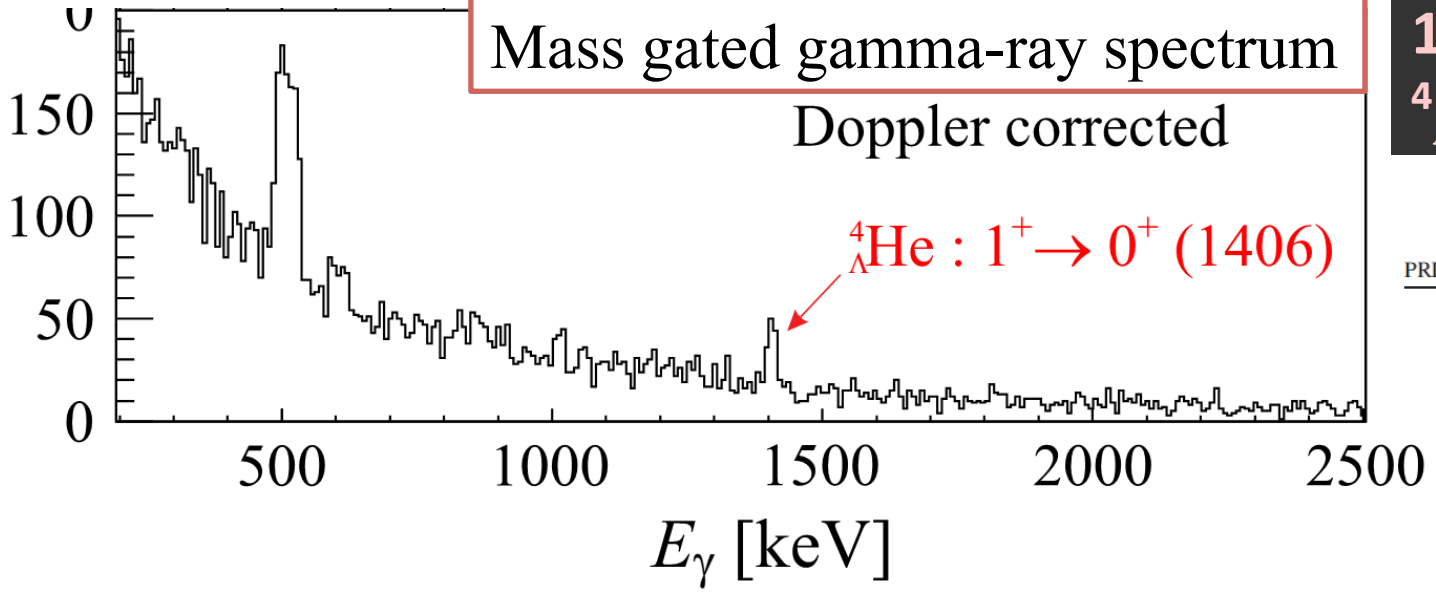
$^{4}_{\Lambda}$He : liq.He target (2.7 g/cm^2)
Total K beam : 23 G kaons
~ 5 days beam time
Just after HD hall resumption
In 2015 April.



Mass gated gamma-ray spectrum



Missing mas spectrum
^{4}He(K^-,π^-)



1406 γ-ray peak was attributed to be $^4_\Lambda$He($1^+ \rightarrow 0^+$) transition

PRL 115, 222501 (2015) PHYSICAL REVIEW LETTERS week ending 27 NOVEMBER 2015

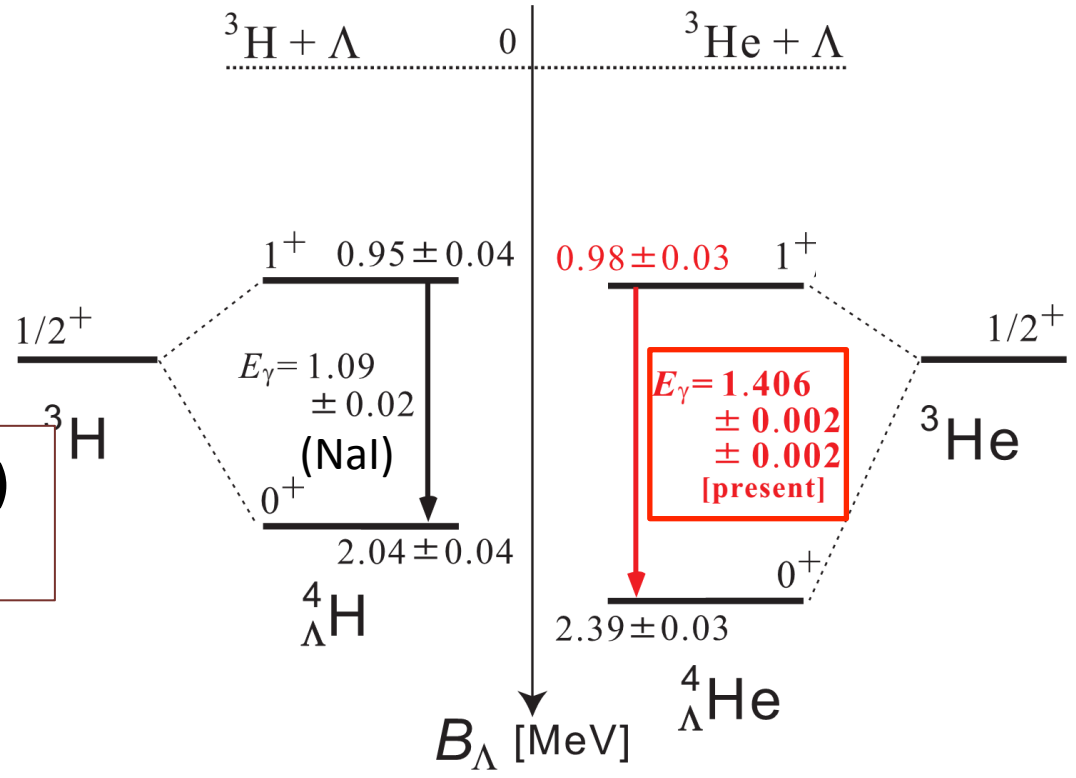
Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of $^4_\Lambda$He

Current level scheme and our finding

$\Delta E_\gamma = E_\gamma(^4_\Lambda\mathrm{He}) - E_\gamma(^4_\Lambda\mathrm{H})$
$= 0.32 \pm 0.02$ MeV

$\Delta B_\Lambda(1^+) = B_\Lambda(^4_\Lambda\mathrm{He}(1^+)) - B_\Lambda(^4_\Lambda\mathrm{H}(1^+))$
$= 0.03 \pm 0.05$ MeV

$\Delta B_\Lambda(0^+) = 0.35 \pm 0.05$ MeV



Charge symmetry breaking is Spin-dependent

Future plan
J-PARC E63

Precision measurement of ${}^{4}_{\Lambda}\mathrm{H}(1^{+}\rightarrow 0^{+})$

Prodcution of ${}^{4}_{\Lambda}\mathrm{He}(1^{+})$ state

- **Direct production on ^{4}He (Single charge exchange reaction)**

  ^{4}He(K^-,π^0) or ^{4}He(π^-,K^0)

  Experimental difficulty to measure scattered particle momenta

- **Hyperfragment (secondary hypernuclei) from highly excited states**

Stopped *K*- absorption (previous NaI exp's method)

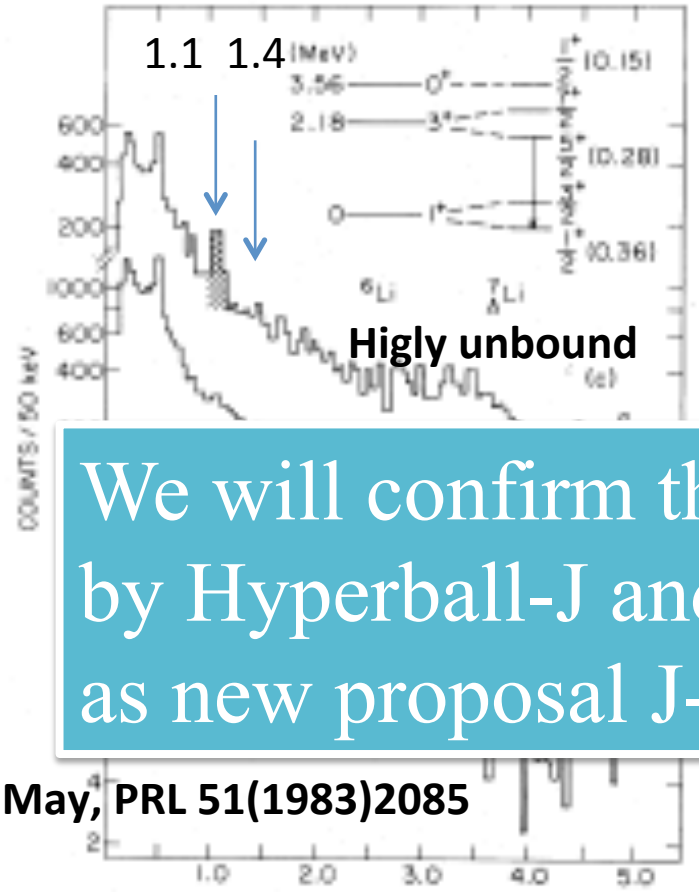
Large momentum transfer (~ 250 MeV/c)=> **Large Doppler broadening of γ-ray peak**

Inflight (*K*-,π-) reaction

Selectivity of momentum transfer region

=> ~ 100 MeV/c @ < 1 GeV/c K- beam => **Small Doppler broadening of γ-ray peak**

Previous $^{4}_{\Lambda}H(1^{+}\rightarrow 0^{+})$ data via inflight (K^{-},π^{-}) on ^{7}Li target



M.May, PRL 51(1983)2085

NaI 74 keV(FWHM) at 1 MeV

Gating highly unbound region of the $^{7}_{\Lambda}Li$ missing mass

1.108 ± 0.010 MeV peak was reported

We will confirm this result with high sensitivity by Hyperball-J and J-PARC K1.1 beam line as new proposal J-PARC E63

MeV) peaks

uster

^{7}Li

K- + α + t -> Λ + ^{3}He + π- + t

$\Lambda + {}^{3}He \rightarrow {}^{4}_{\Lambda}He$ (0^{+} only non-spin-flip)

$\Lambda + t \rightarrow {}^{4}_{\Lambda}H$ (Both 0+/1+ ratio =1:3 expected)

$\Rightarrow {}^{4}_{\Lambda}H\ (1^{+}\rightarrow 0^{+})$ dominant on gamma-spectrum

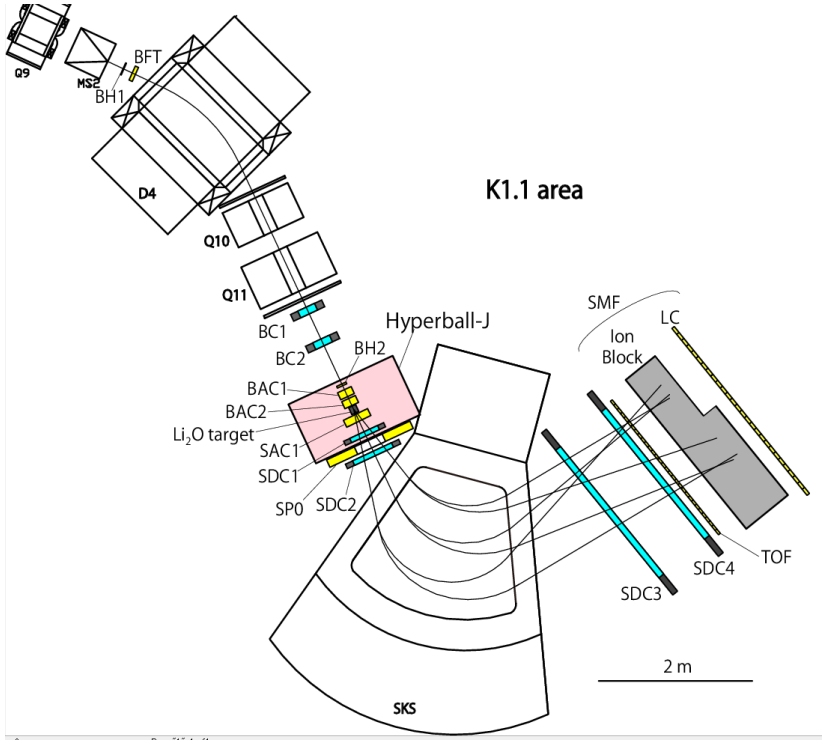
J-PARC Hadron hall
K1.1 beam line setup

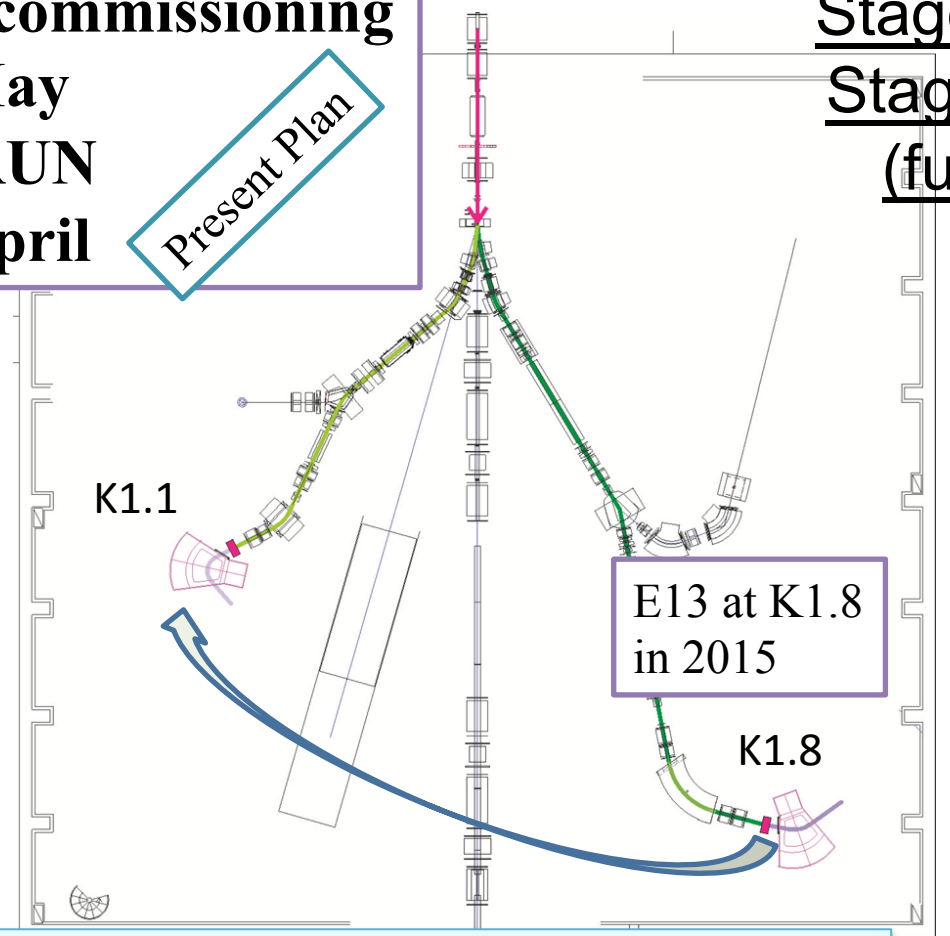
K1.1 Beam line @ 50 kW	
1.1 GeV/c	180 k/spill
0.9 GeV/c	60 k/spill

K1.1/SKS commissioning
~2018.May
E63 $^{4}_{\Lambda}$H RUN
~ 2018.April

Present Plan

J-PARC E63
Submitted in Dec. 2015
Stage-1 Jan. 2016
Stage-2 Jul. 2016
(full approval)





π- spectrometer SKS and
Ge array Hyperball move from K1.8 to K1.1

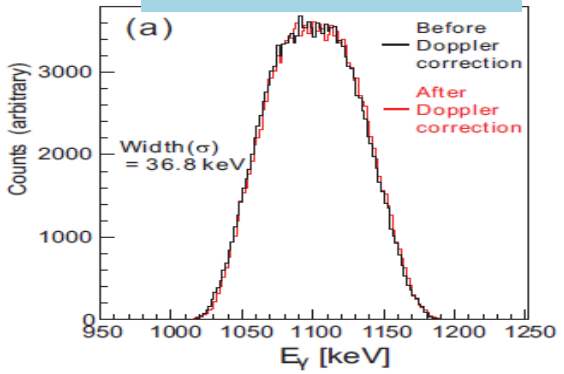
Detectors are the same as E13
Only minor modification

Comparison with Experimental conditions for $^{4}_{\Lambda}H(1^{+}\rightarrow 0^{+})$

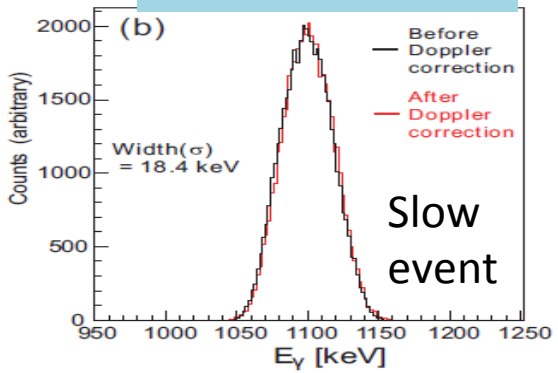
	BNL experiment	E63 (present work)
# K beam	10 G Kaons	5 G Kaons (6 days)
Target thickness	8 g/cm^2 (natural)	15 g/cm^2 (enrich)
γ-ray efficiency	6%	~ 6%
Effective π− acceptance	< 18 msr ?	~35 msr (SKS < 6°selection)
γ peak counts	**150 counts**	**> 300 counts ~ 75 (Slow event)**
Resolution	**NaI** 40 keV(σ)	**Ge** 2 keV(σ)
Doppler broad	37 keV(σ)	18 keV(σ)
Peak width	**54 keV(σ)**	**18 keV(σ)**

By selecting the excitation Energy tightly, Doppler broad width can be controlled.

Eex = 22- 39 MeV



Eex = 20- 25 MeV



Summary

Charge Symmetry Breaking
in ΛN interaction is studied through the $^{4}_{\Lambda}$H/$^{4}_{\Lambda}$He structures

New data of E13 at K1.8,
Excitation energy $^{4}_{\Lambda}$He(1^{+}) = 1.406(5) MeV

Exsistence of large CSB and its spin-dependence was confirmed

E63 at K1.1 is proposed to determine the excitation energy of $^{4}_{\Lambda}$H(1^{+}) precisely and planed in 2018 spring.

J-PARC E13 collaboration

T. O. Yamamoto,[1] M. Agnello,[2,3] Y. Akazawa,[1] N. Amano,[4] K. Aoki,[5] E. Botta,[3,6] N. Chiga,[1] H. Ekawa,[7] P. Evtoukhovitch,[8] A. Feliciello,[3] M. Fujita,[1] T. Gogami,[7] S. Hasegawa,[9] S. H. Hayakawa,[10] T. Hayakawa,[10] R. Honda,[10] K. Hosomi,[9] S. H. Hwang,[9] N. Ichige,[1] Y. Ichikawa,[9] M. Ikeda,[1] K. Imai,[9] S. Ishimoto,[5] S. Kanatsuki,[7] M. H. Kim,[11] S. H. Kim,[11] S. Kinbara,[12] T. Koike,[1] J. Y. Lee,[13] S. Marcello,[3,6] K. Miwa,[1] T. Moon,[13] T. Nagae,[7] S. Nagao,[1] Y. Nakada,[10] M. Nakagawa,[10] Y. Ogura,[1] A. Sakaguchi,[10] H. Sako,[9] Y. Sasaki,[1] S. Sato,[9] T. Shiozaki,[1] K. Shirotori,[14] H. Sugimura,[9] S. Suto,[1] S. Suzuki,[5] T. Takahashi,[5] H. Tamura,[1] K. Tanabe,[1] K. Tanida,[9] Z. Tsamalaidze,[8] M. Ukai,[1] Y. Yamamoto,[1] and S. B. Yang[13]

(J-PARC E13 Collaboration)

[1]*Department of Physics, Tohoku University, Sendai 980-8578, Japan*
[2]*Dipartimento di Scienza Applicate e Tecnologica, Politecnico di Torino, Corso Duca degli Abruzzi, 10129 Torino, Italy*
[3]*INFN, Sezione di Torino, via P. Giuria 1, 10125 Torino, Italy*
[4]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[5]*Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*
[6]*Dipartimento di Fisica, Universit di Torino, Via P. Giuria 1, 10125 Torino, Italy*
[7]*Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[8]*Joint Institute for Nuclear Research, Dubna, Moscow Region 141980, Russia*
[9]*Advanced Science Research Center (ASRC), Japan Atomic Agency (JAEA), Tokai, Ibaraki 319-1195, Japan*
[10]*Department of Physics, Osaka University, Toyonaka 560-0043, Japan*
[11]*Department of Physics, Korea University, Seoul 136-713, Korea*
[12]*Faculty of Education, Gifu University, Gifu 501-1193, Japan*
[13]*Department of Physics and Astronomy, Seoul National University, Seoul 151-747, Korea*
[14]*Research Center of Nuclear Physics, Osaka University, Ibaraki 567-0047, Japan*

J-PARC E63 collaboration

31 participants from 12 institutes

Y. Akazawa, M. Fujita, N. Ichige, M. Ikeda, T. Koike, K. Miwa, Y. Ogura,
H. Tamura(spokesperson), Y. Sasaki, S. Suto, T. Yamamoto
Department of Physics, Tohoku University, Japan

S. Nagao

K. Aoki, T. Takahashi, M. Ukai
Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK), Japan

K. Hosomi, K. Tanida
Advanced Science Research Center, Japan Atomic Energy Agency (JAEA), Japan

S. Sato

P. Evtoukhovitch, Z. Tsamalaidze
Joint Institute for Nuclear Research, Russia

S. Yang J.Y Lee, T.J. Moon
Department of Physics and Astronomy, Seoul National University, Korea

R. Honda
Department of Physics, Osaka University, Japan

K. Shirotori
Research Cetner for Nuclear Physics, Osaka University, Japan

E. Botta
Dipartimento di Fisica, Universitá di Torino, and
Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, Italy

A. Feliciello
Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, Italy

M. Agnello
Dipartimento di Scienze Applicate e Tecnologia, Politecnico di Torino, Italy

J.K. Ahn, S.H. Kim
Korea University, Korea

T. Wang
Beihang University, China

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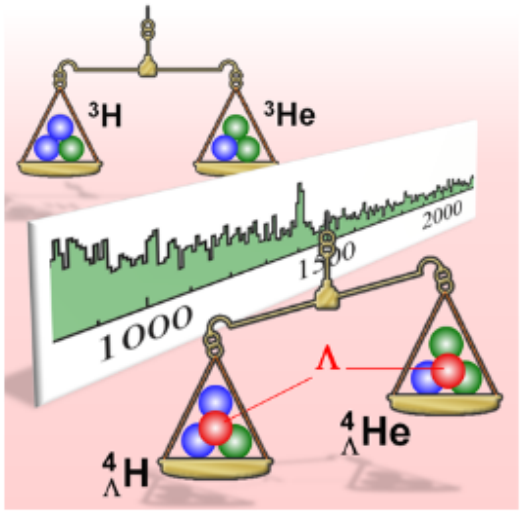

EDITORS' SUGGESTION

Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of $^4_\Lambda$He

The energy spacing of the spin-doublet states in the $^4_\Lambda$He hypernucleus indicate a large spin dependent charge symmetry breaking in the ΛN interaction.

T. O. Yamamoto *et al.* (J-PARC E13 Collaboration)

Phys. Rev. Lett. **115**, 222501 (2015)

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