Study of charge symmetry breaking in ΛN interaction via the gamma-ray spectroscopy of $^{4}_{\Lambda}$He

2015/9/7

T. O. Yamamoto

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and the E13 collaboration

J-PARC E13 collaboration

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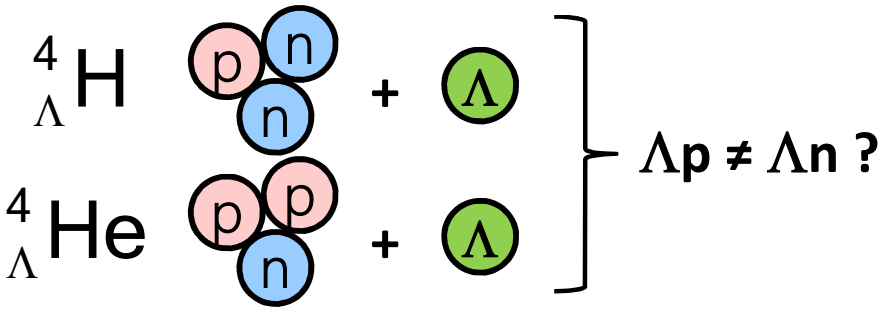
- **Experiment at J-PARC (E13)**
- **Result of the 2015 physics run**
  - New data on the excitation energy of $^{4}_{\Lambda}$He(1^{+})
- **Summary**

Charge symmetry breaking (CSB) in ΛN-interaction (A=4 system)

Unexpectedly large difference in excitation energies (E_γ) and Λ-binding energies (B_Λ) between the mirror hypernuclei.

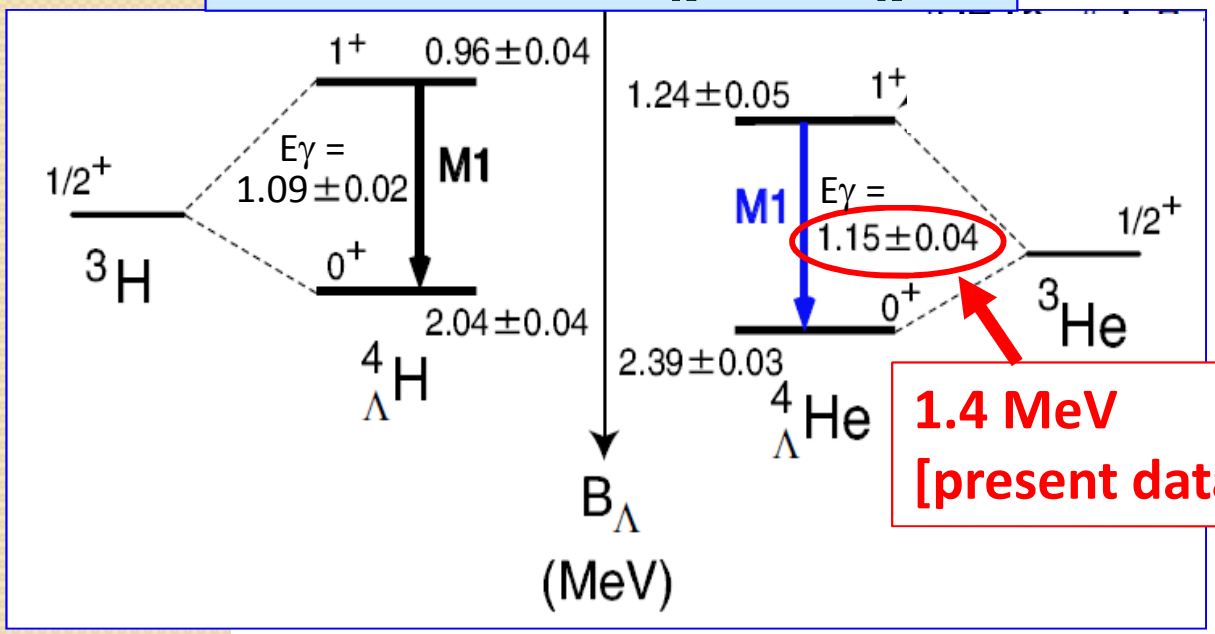


$\Delta B_\Lambda (0^+) = 0.35$ MeV , $\Delta B_\Lambda (1^+) = 0.28$ MeV

Still an open question

A. R. Bodmer and Q. N. Usmani, Phys. Rev. C31 (1985) 1400.
B. F. Gibson and D. R. Lehman, Phys. Rev. C37 (1988) 679.
A. Nogga, H. Kamada, and W. Gloockle, Phys. Rev. Lett. 88, 172501 (2002)

Level scheme of $^4_\Lambda$H and $^4_\Lambda$He



1.4 MeV [present data]

Considering
- Coulomb force
- ΛN-ΣN coupling

with widely used NSC97e

Many theoretical efforts, but inconsistent with data

Need re-examination of existing data

CSB effect in $B_\Lambda(0^+)$

- **Large difference in $B_\Lambda(0^+)$ energies :**

  $\Delta B_\Lambda(0^+)$ =350 keV (emulsion data)

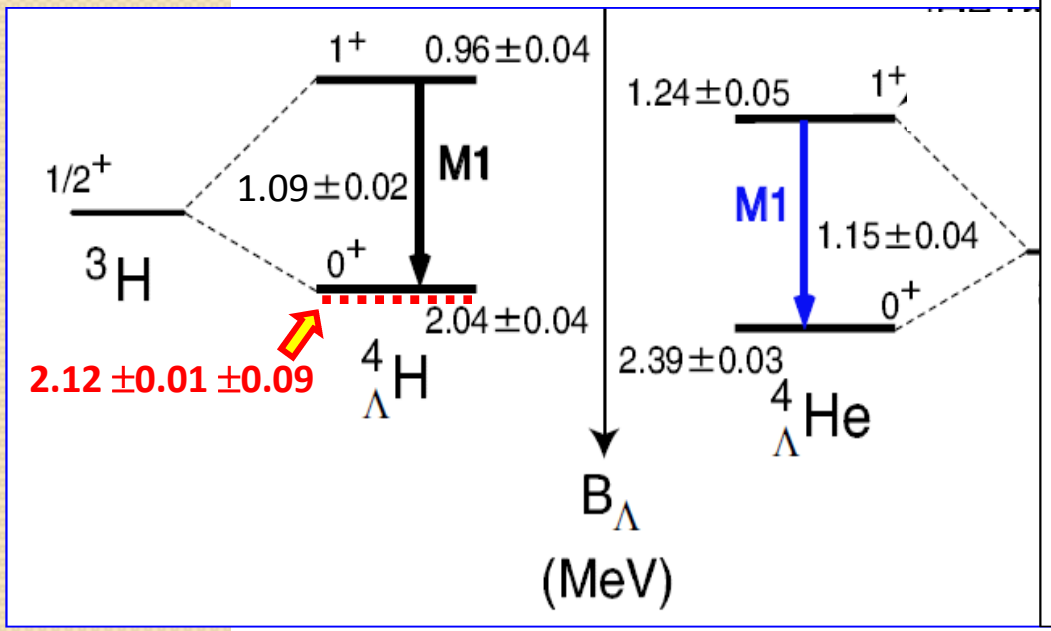
M. Juric et al.,
Nucl. Phys. B 52, 1 (1973)

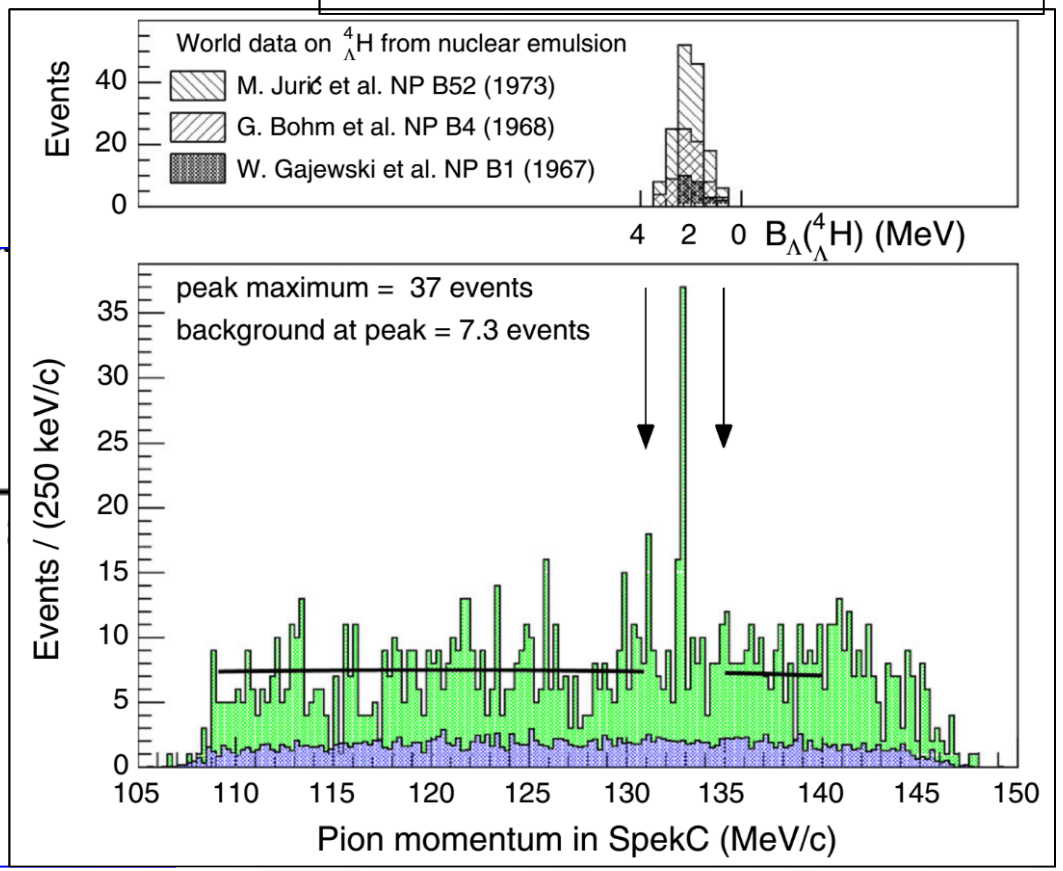
- **Recently precise measurement of $B_\Lambda(^4_\Lambda H(0+))$ at MAMI-C via the decay π- spectroscopy method**

  $B_\Lambda(^4_\Lambda H(0+)) = 2.12 \pm 0.01 \pm 0.09$ MeV

A. Esser, S. Nagao et al.,
Phys. Rev. Lett. 114, 232501 (2015)

Indication of CSB





Old experiments for $E_\gamma(^4_\Lambda H)$

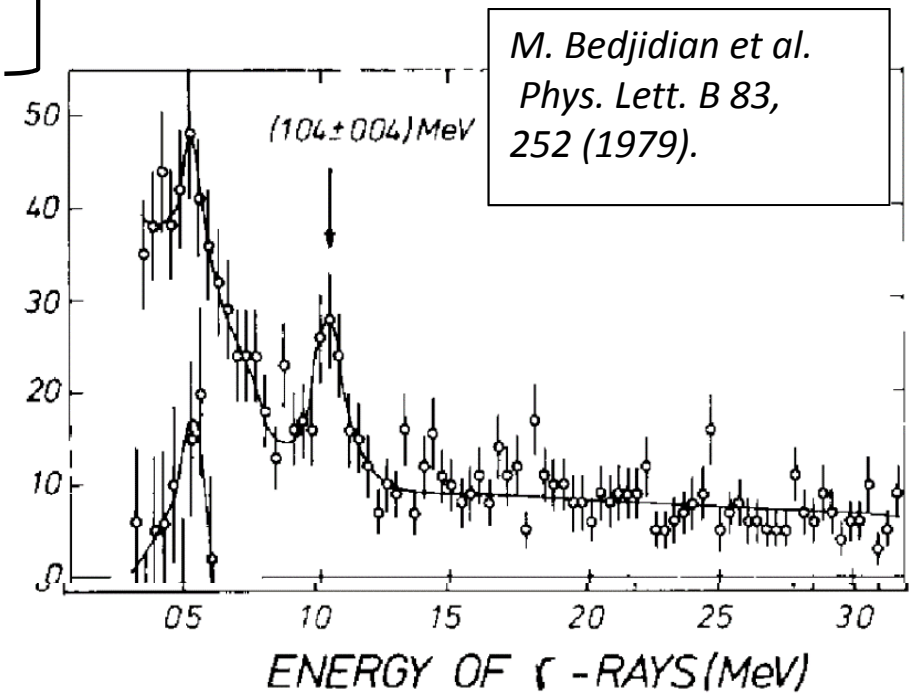
Three experiments were performed

	excitation energy [MeV]
Bedjian et al. (1976)	1.09 (0.03)
Bedjian et al. (1979)	1.04 (0.04)
A. Kawachi (1997) *Doctoral thesis*	1.114 (0.030)

3 independent experiments reported at 1.1 MeV

- Stopped K reaction (Li target)
  → Tagging π- from $^4_\Lambda H$ decay
- NaI detector

Averaged value : 1.09 (0.02) MeV



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

Old experiment for $E_\gamma(^4_\Lambda He)$

Only one experiment was performed

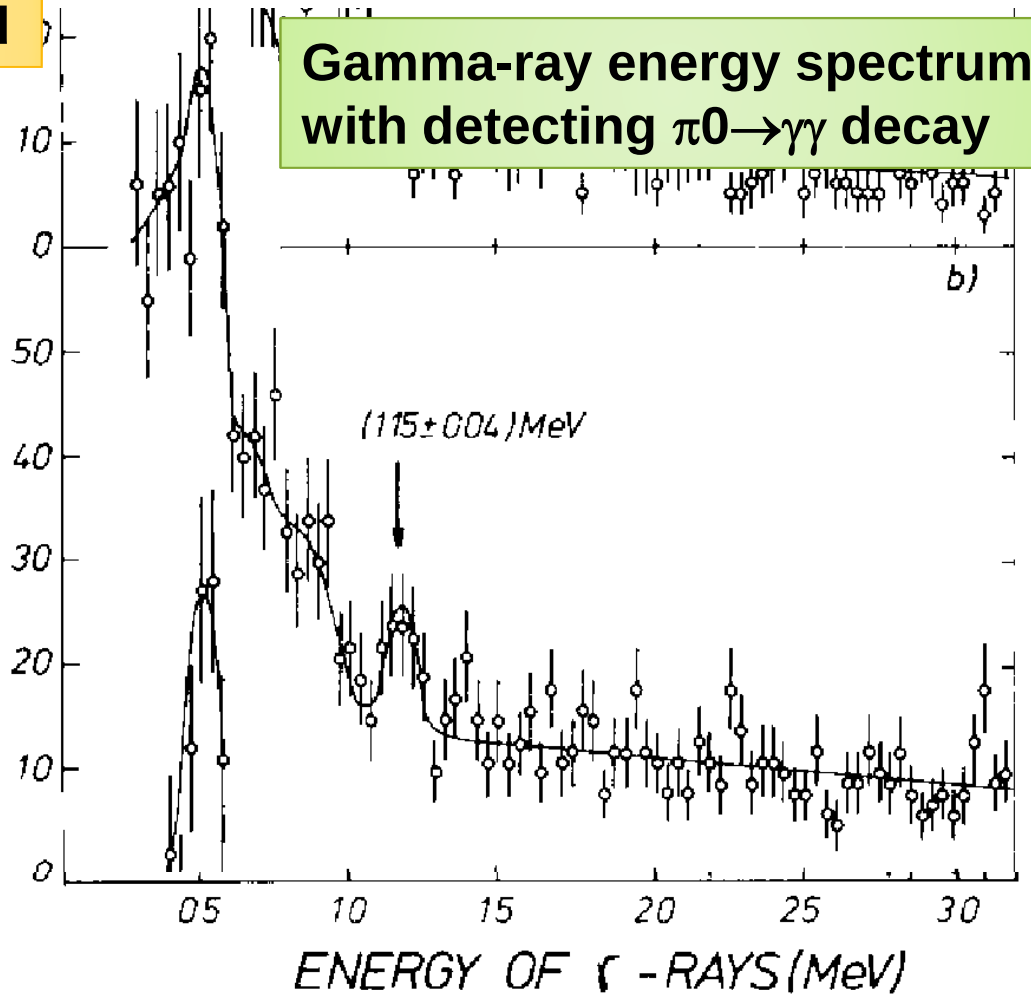
- Stopped K- reaction (Li target)
  - detecting $\pi 0 \rightarrow \gamma\gamma$ (with Pb + scinti. sandwich) for tagging hypernuclei
  - Doppler broaden γ peak
- NaI detector
  - Energy resolution : 12% (^{8}Li* : 0.98 MeV)
- Limited statistics

Higher sensitivity and statistics can be achieved by

- In-flight ^{4}He(K-,π-)$^4_\Lambda$He reaction
- Ge detector (Energy resolution : 0.2%)
- High intensity K beam

  + large acceptance spectrometers

Gamma-ray energy spectrum with detecting $\pi 0 \rightarrow \gamma\gamma$ decay



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

reported value : 1.15 (0.04) MeV

The J-PARC E13 experiment

Experimental setup (E13)

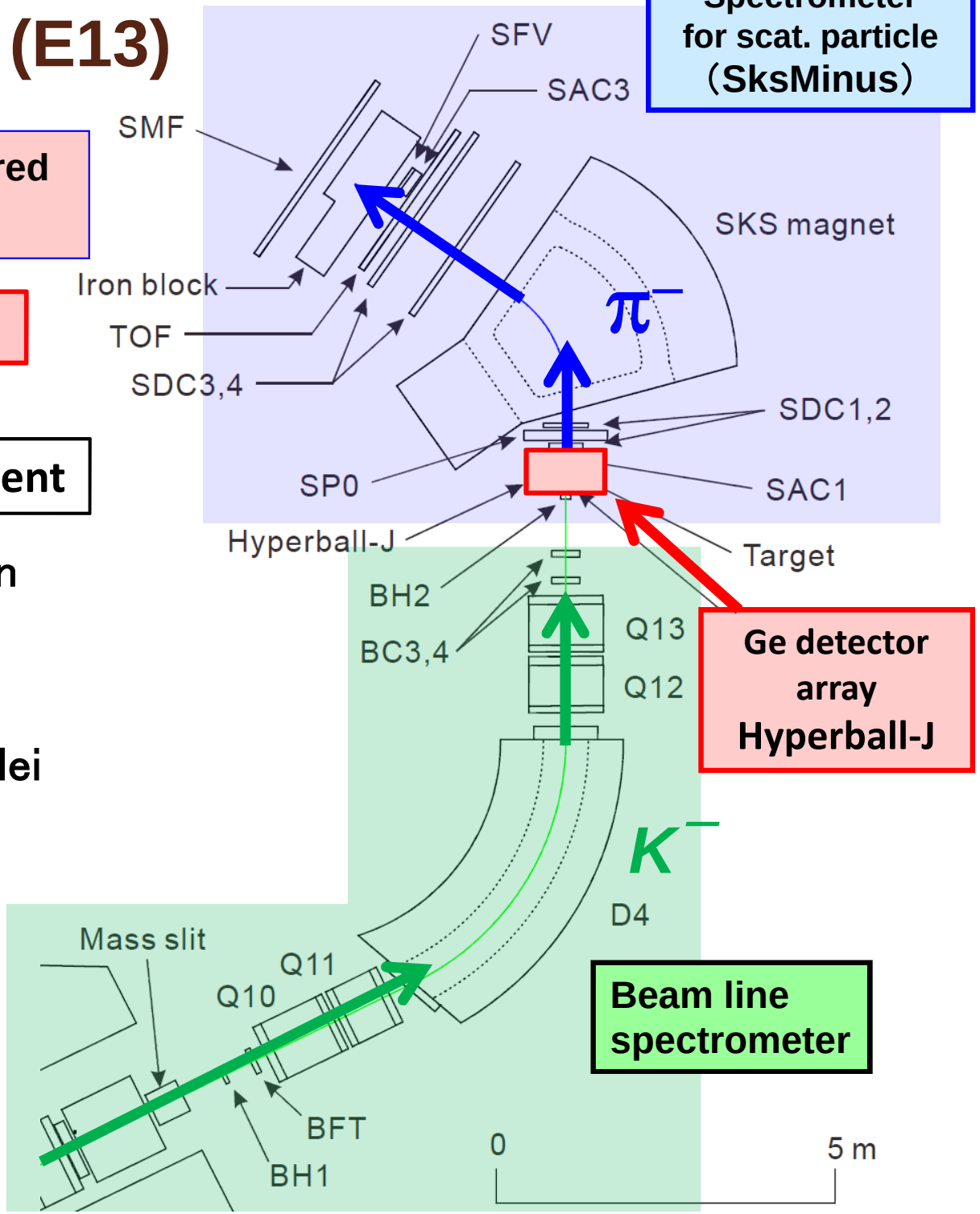
Use high intensity K- beam delivered from J-PARC K1.8 beam line

$$^{A}Z(K^{-},\pi^{-})\,^{A}_{\Lambda}Z^{*} \rightarrow {}^{A}_{\Lambda}Z + \gamma$$

reaction-γ coincidence experiment

- Tag hypernuclear production
  - Beam line spectrometer
  - SksMinus spectrometer
- Detect γ ray from hypernuclei
  - Hyperball-J

$^{4}_{\Lambda}$He : liq.He target (2.7 g/cm^2)
p_K = 1.5 GeV/c



Time line of the E13 experiment

2012.8 **Installation of Hyperball-J**

2013.1 **Installation of SksMinus detectors**

2013.3-5 **Commissioning beam time**

whole system was checked

(suspend just before physics run)

2015.4 **Physics run with a ^{4}He target**

This talk

- **γ-ray spectroscopy of $^4_\Lambda$He**

- **missing mass spectroscopy of $^4_\Sigma$He**

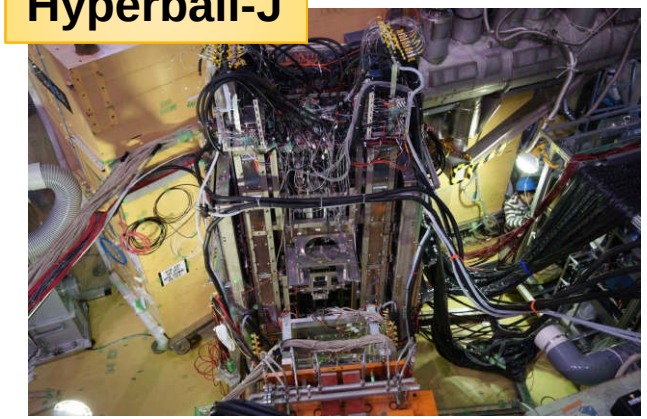
Irradiated K-beam : 23 G

(Total beam time = ~5 days)

2015.6 **Physics run with a CF_4 target**

- **γ-ray spectroscopy of $^{19}_\Lambda$F**

Hyperball-J



SksMinus(downstream)

M. Nakagawa

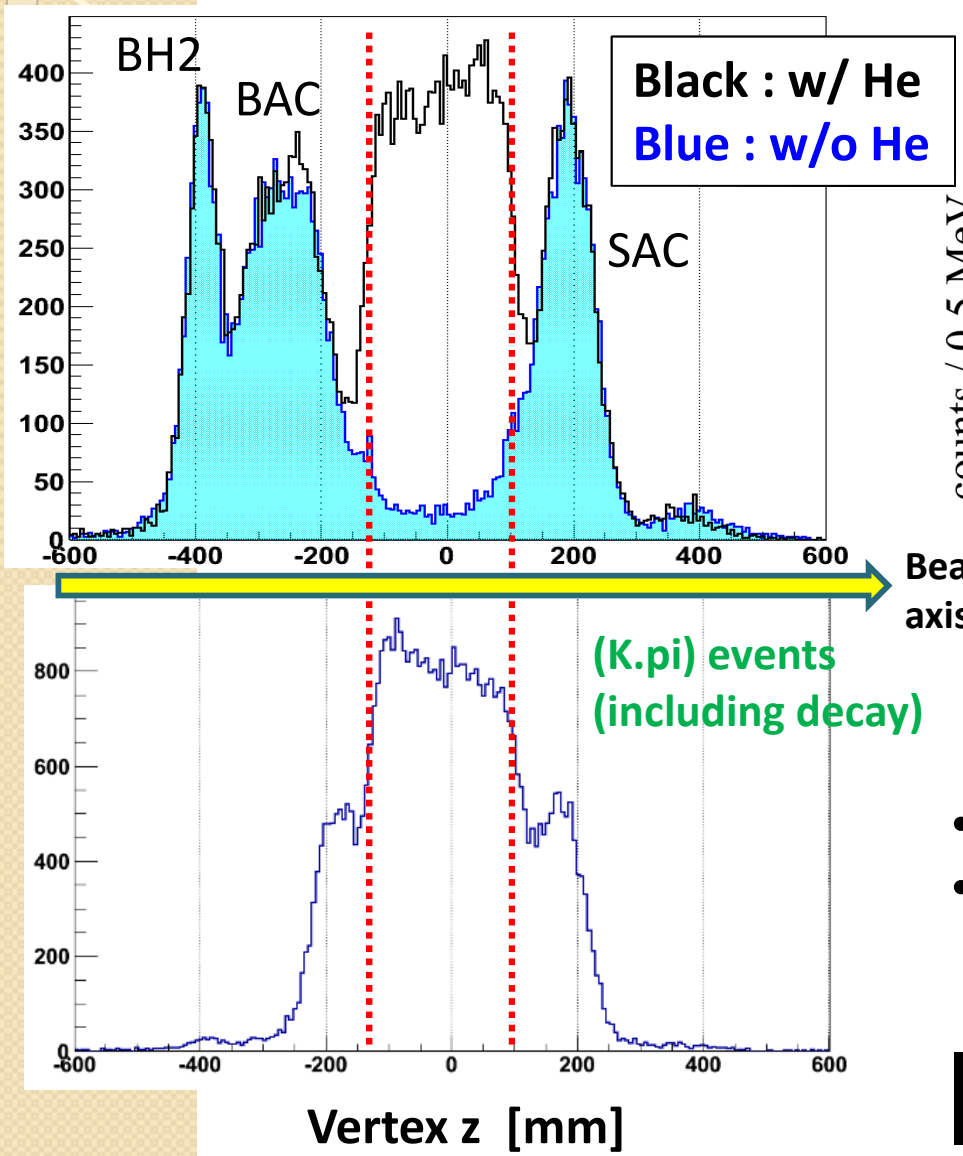
S.B. Yang

Y. Sasaki (poster)

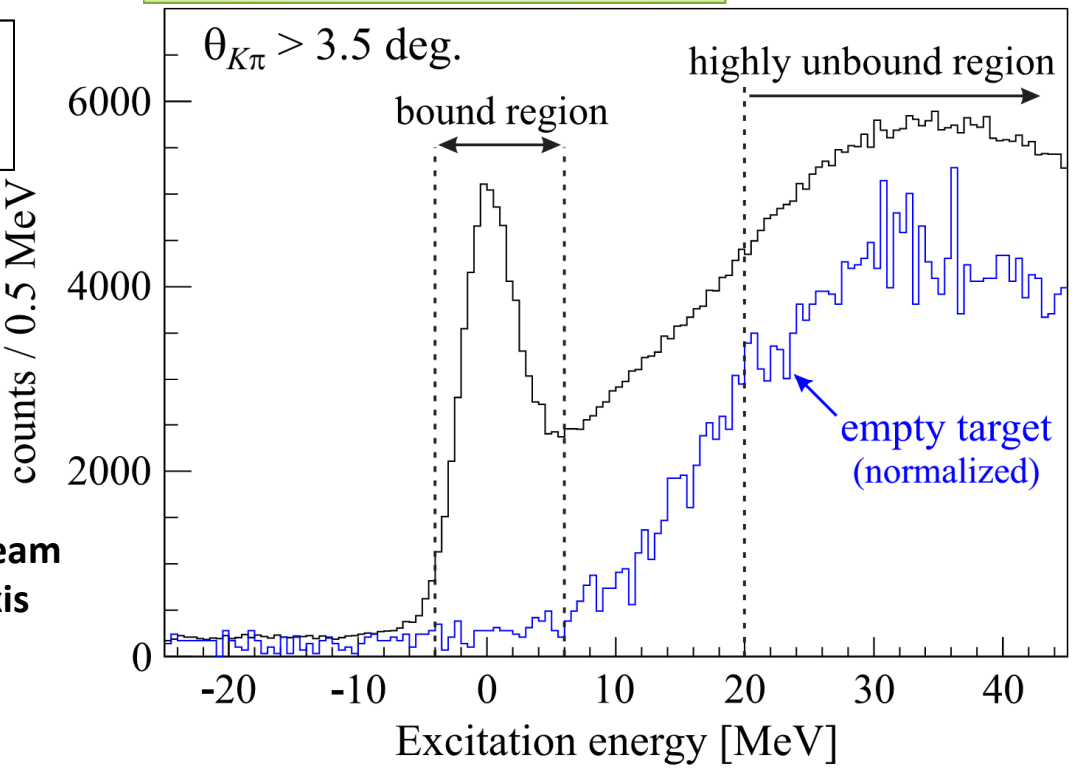
Identification of $^{4}_{\Lambda}$He production

Reaction vertex (beam axis)

Beam scat. events



Missing mass spectrum for ^{4}He(K-,π-)X

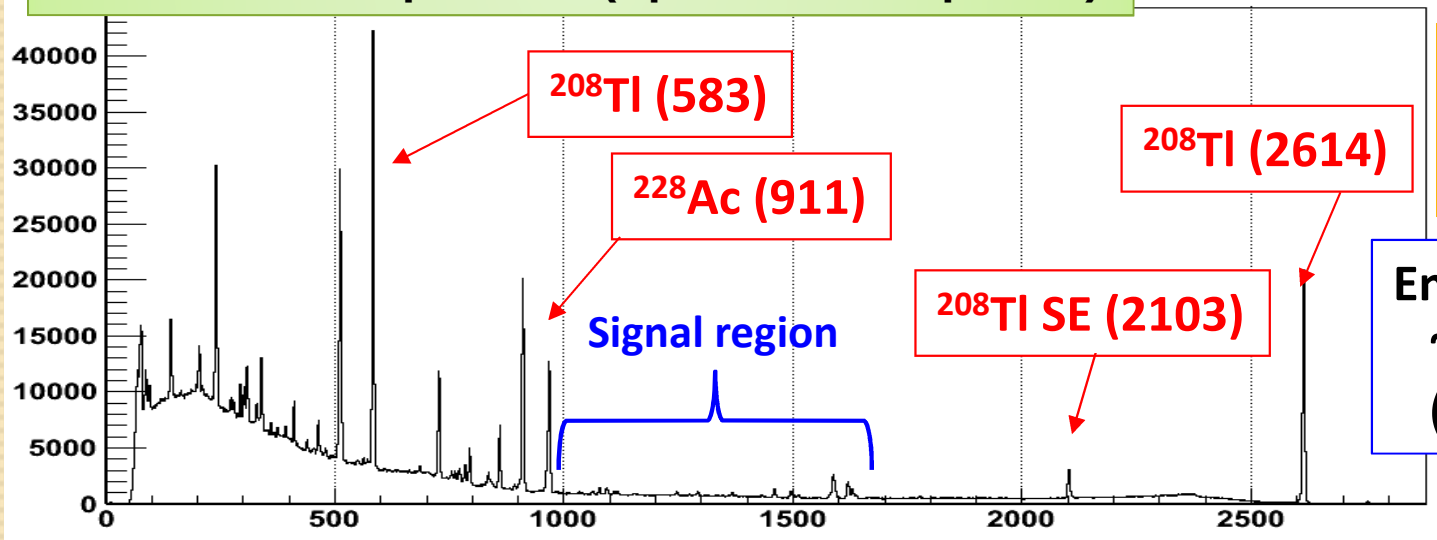


- **Missing mass resolution : 5 MeV (FWHM)**
- **Small mount of B.G. contamination in "bound region" (10 MeV gate)**

We can clearly select $^{4}_{\Lambda}$He bound events.

Gamma-ray measurement

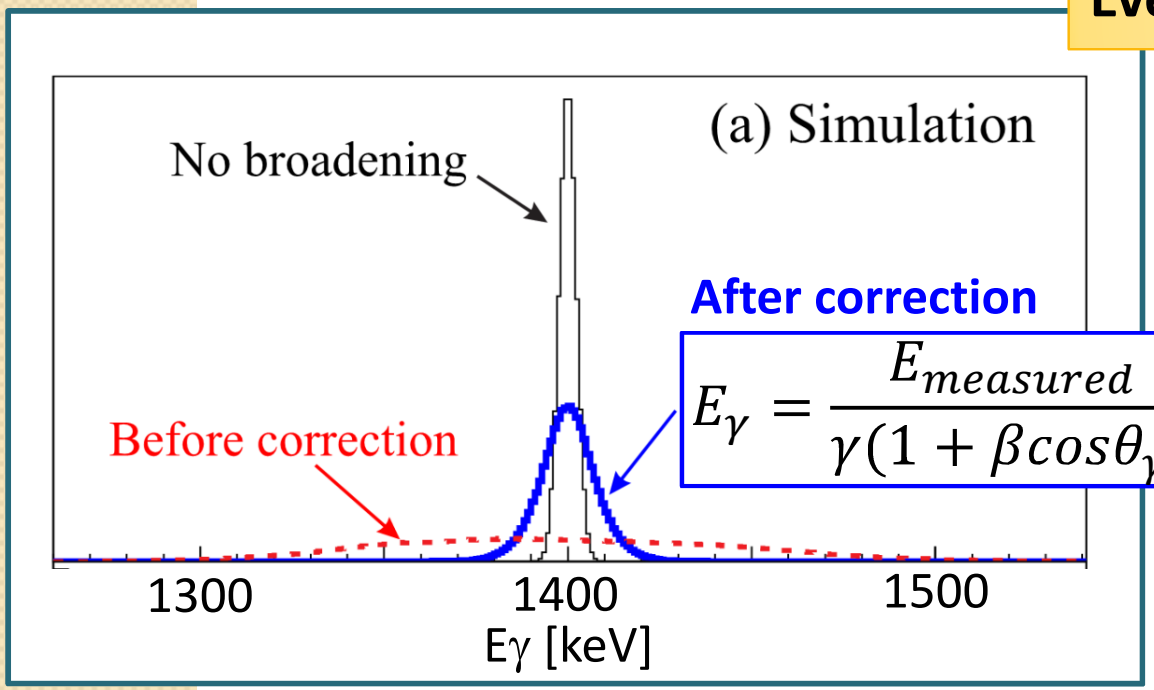
Ge calibration spectrum (Spill-off beam period) (1h data taking)

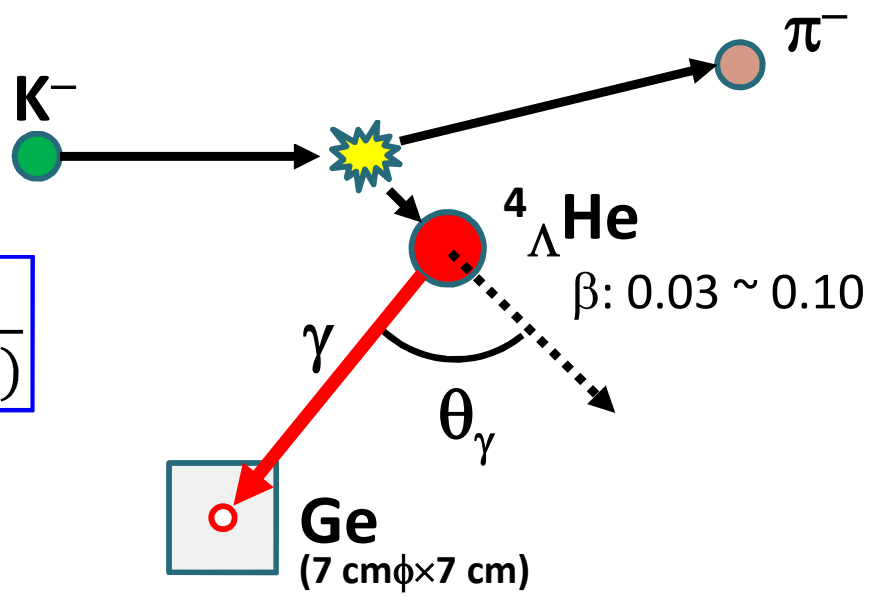


Run-by-run calibration with Th-series source

Energy resolution :
~5 keV (FWHM) @ 1.4 MeV
(summing all detectors)

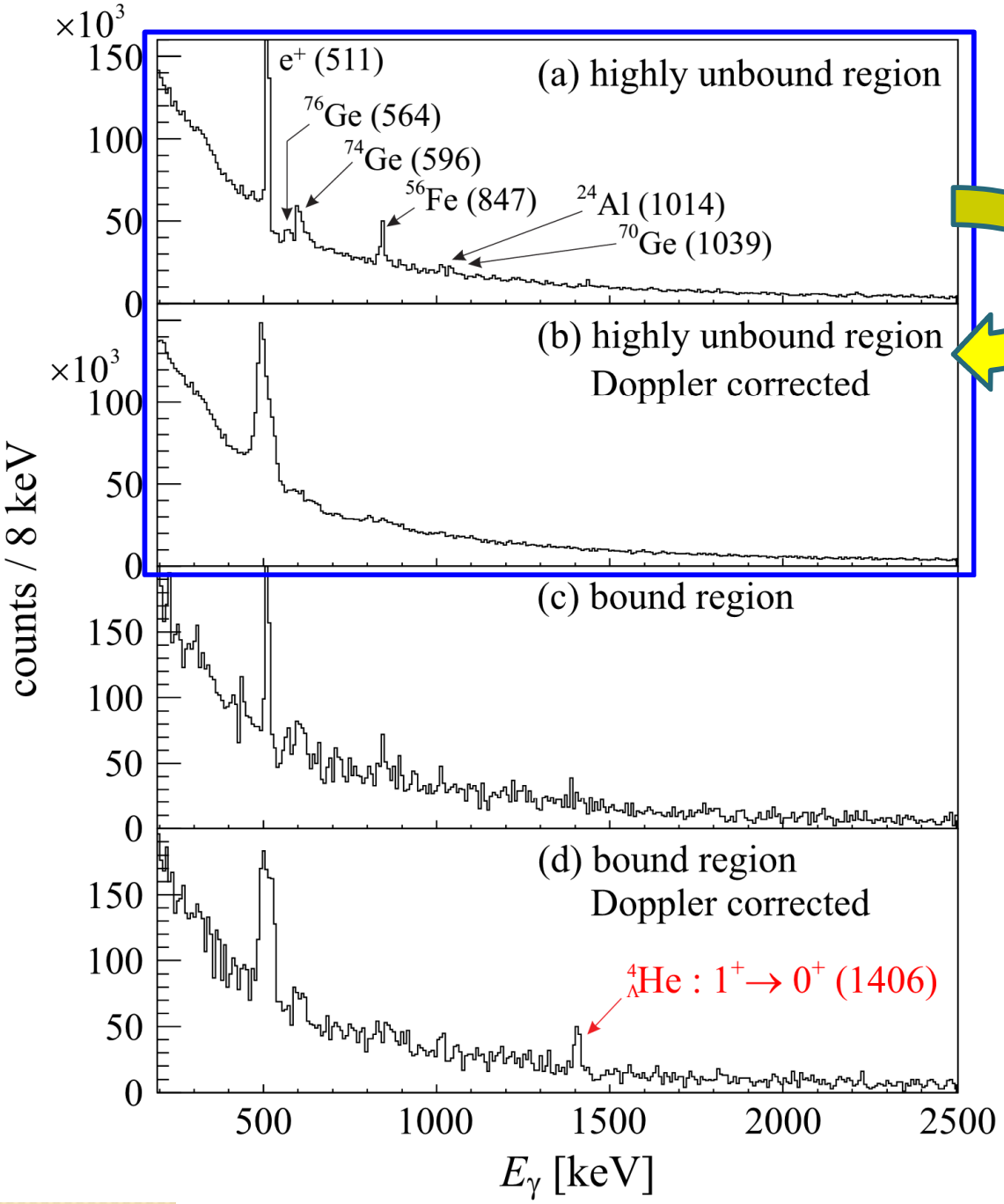
Event-by-event Doppler correction





Result

Mass gated gamma-ray spectrum

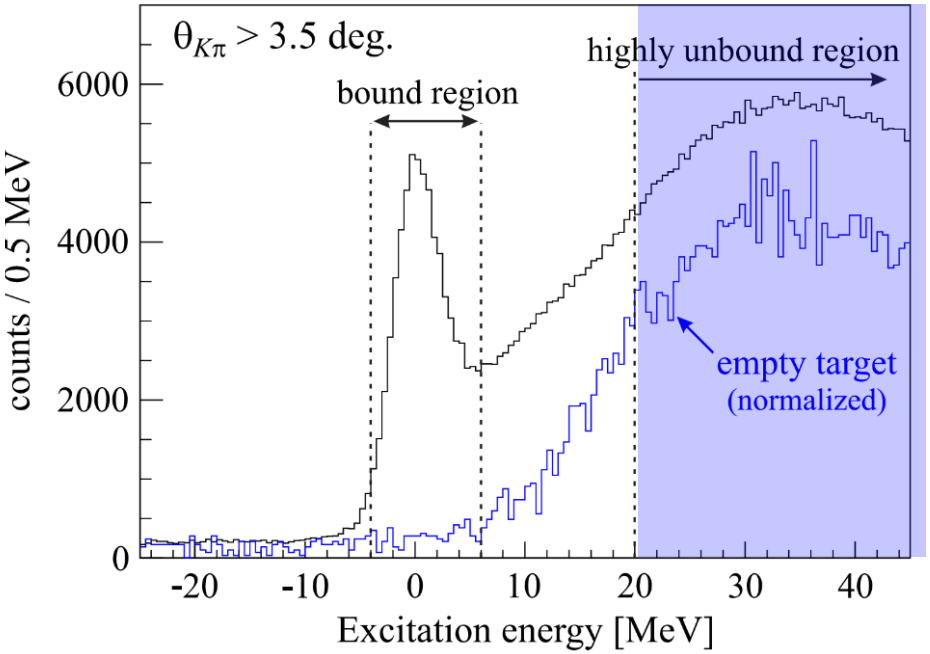


Gamma rays from non-strange nuclei (accidental coincidence)

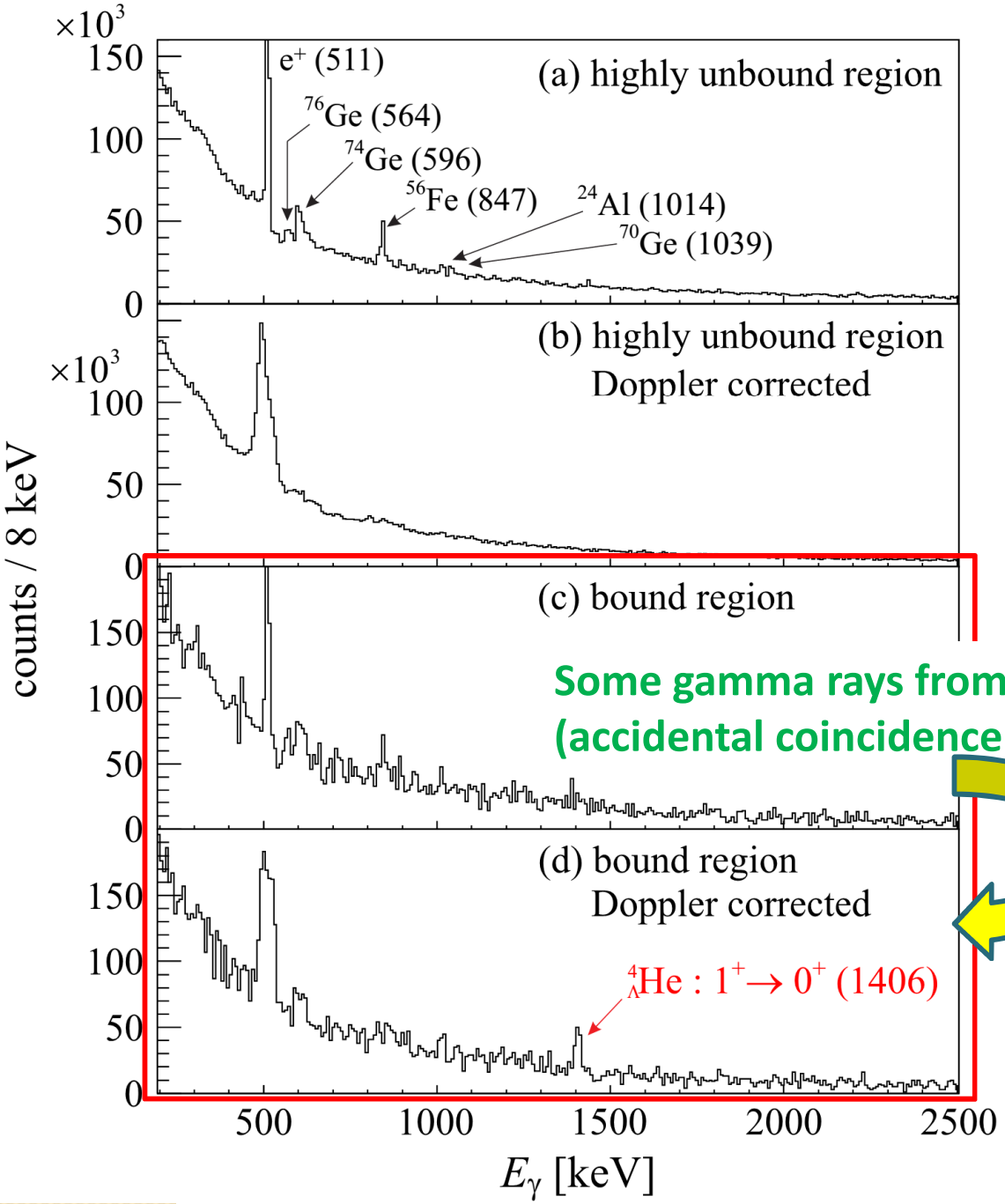
Doppler correction

No peak structure

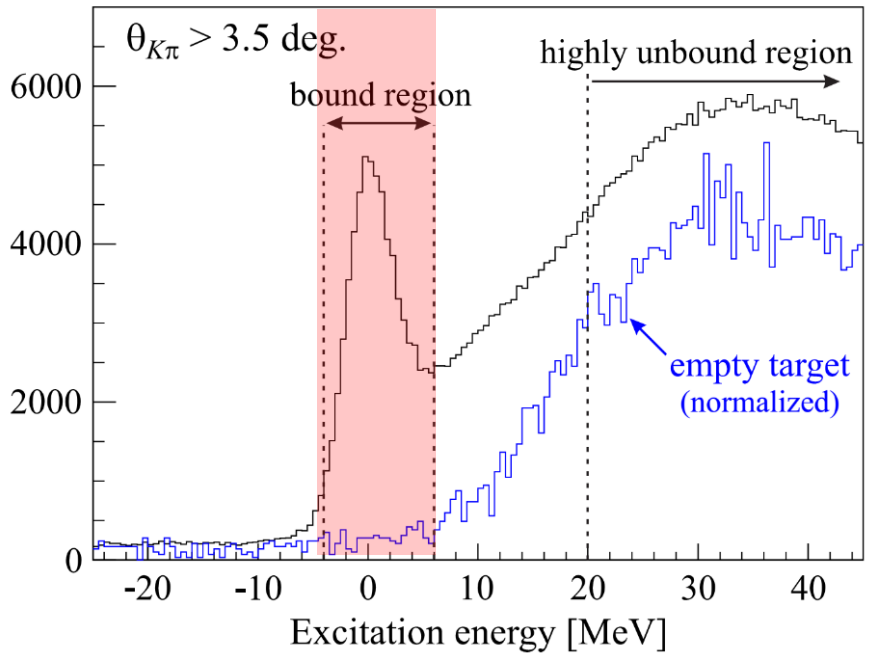
Mass gate



Mass gated gamma-ray spectrum



Mass gate



Some gamma rays from non-strange nuclei (accidental coincidence)

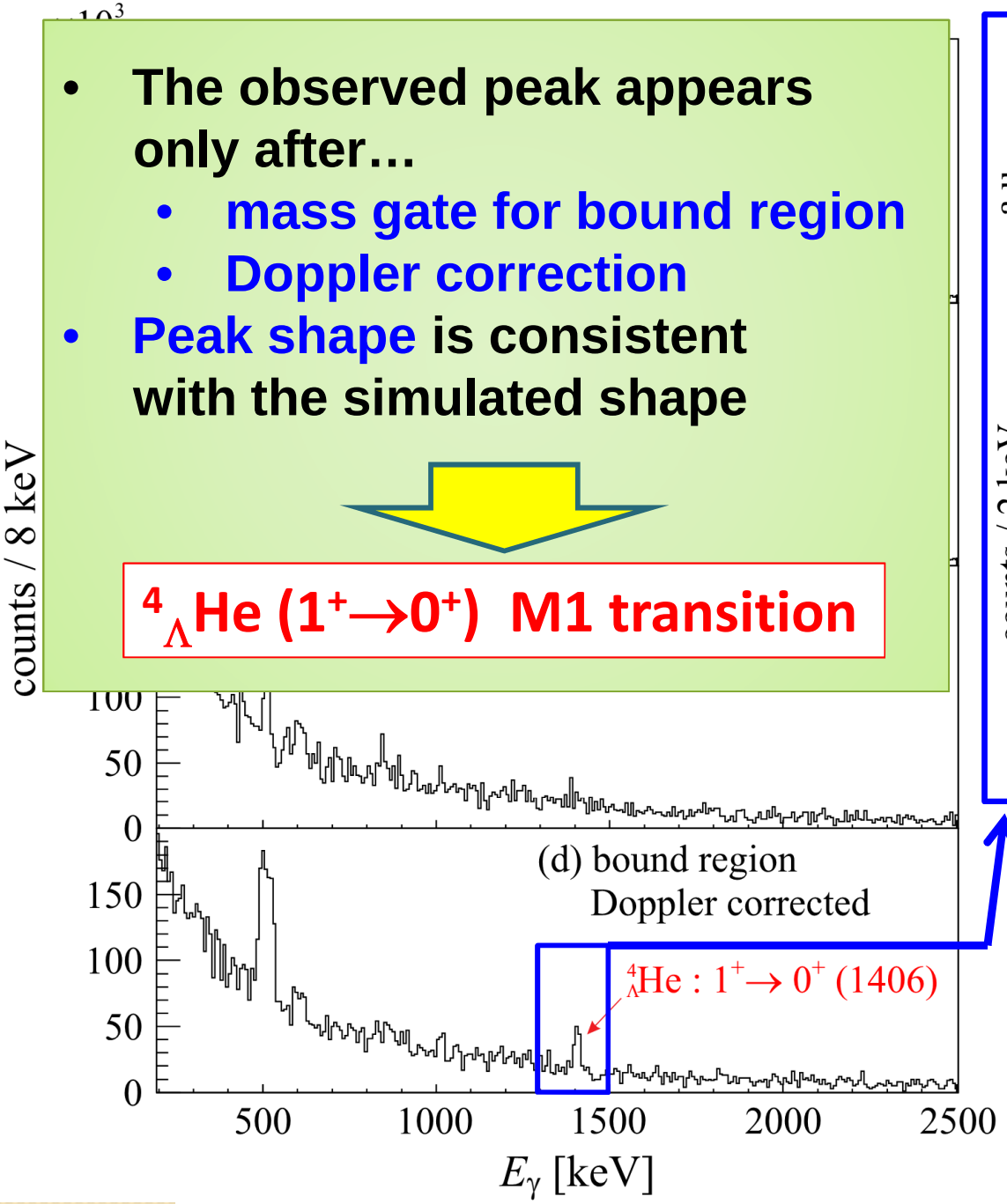
Doppler correction

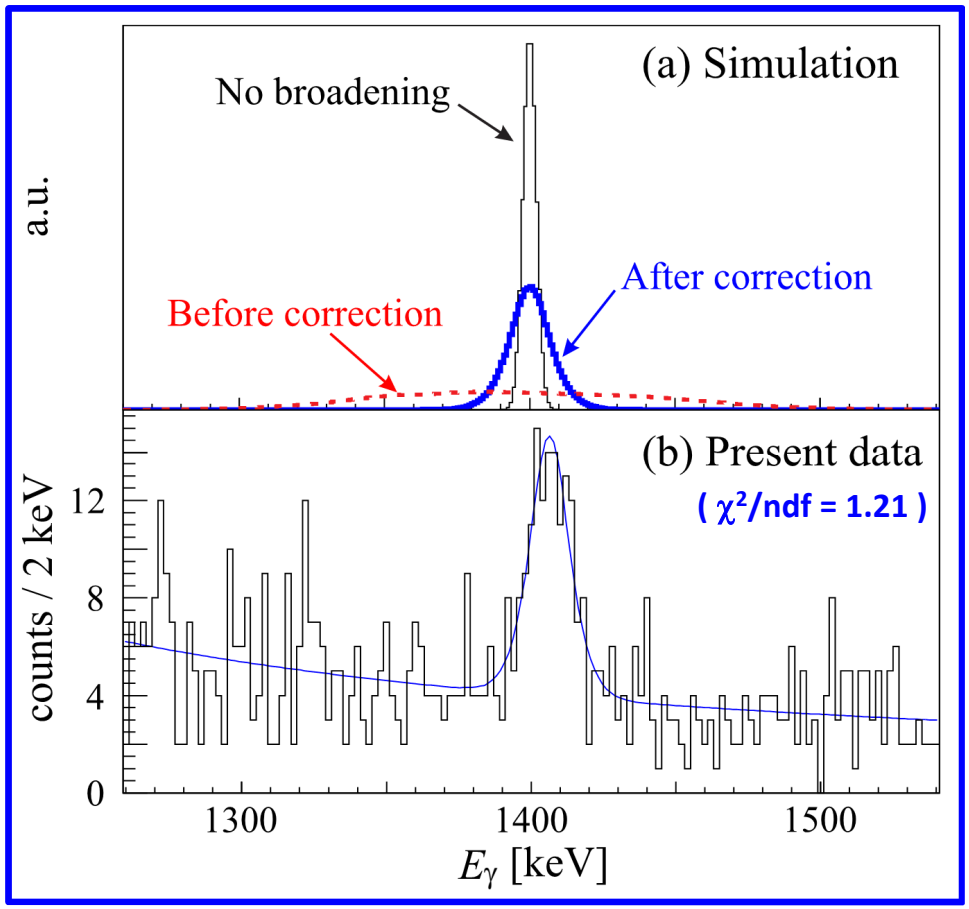
Single peak was observed.

Mass gated gamma-ray spectrum

- The observed peak appears only after…
  - mass gate for bound region
  - Doppler correction
- Peak shape is consistent with the simulated shape

$^{4}_{\Lambda}$He ($1^{+}\rightarrow 0^{+}$) M1 transition



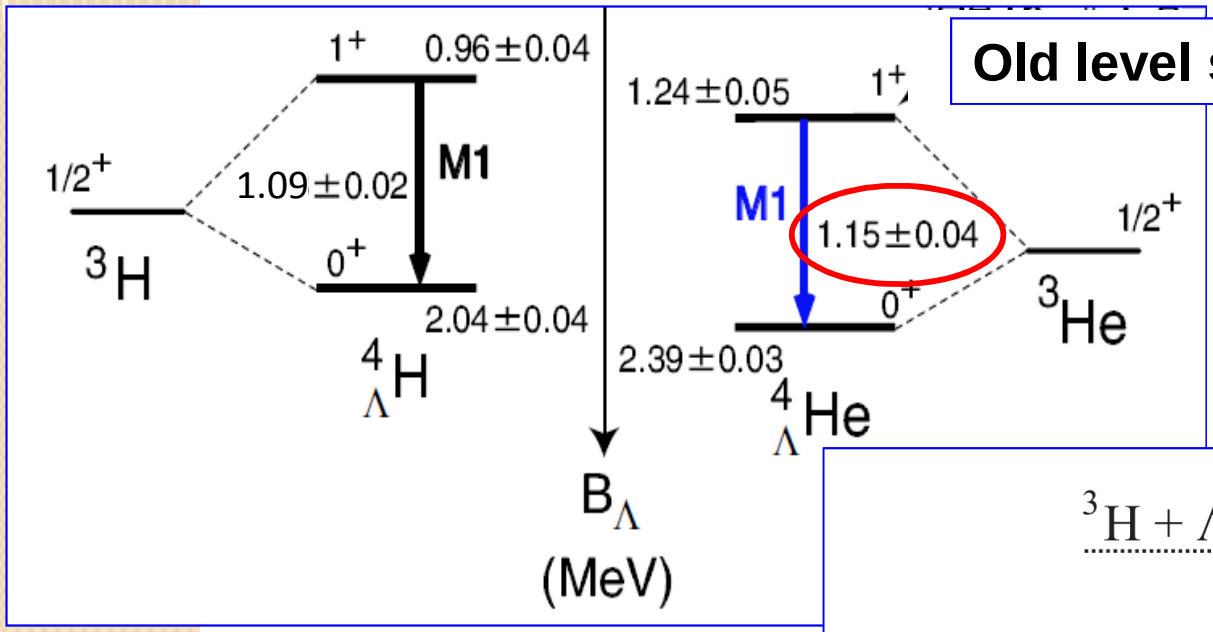


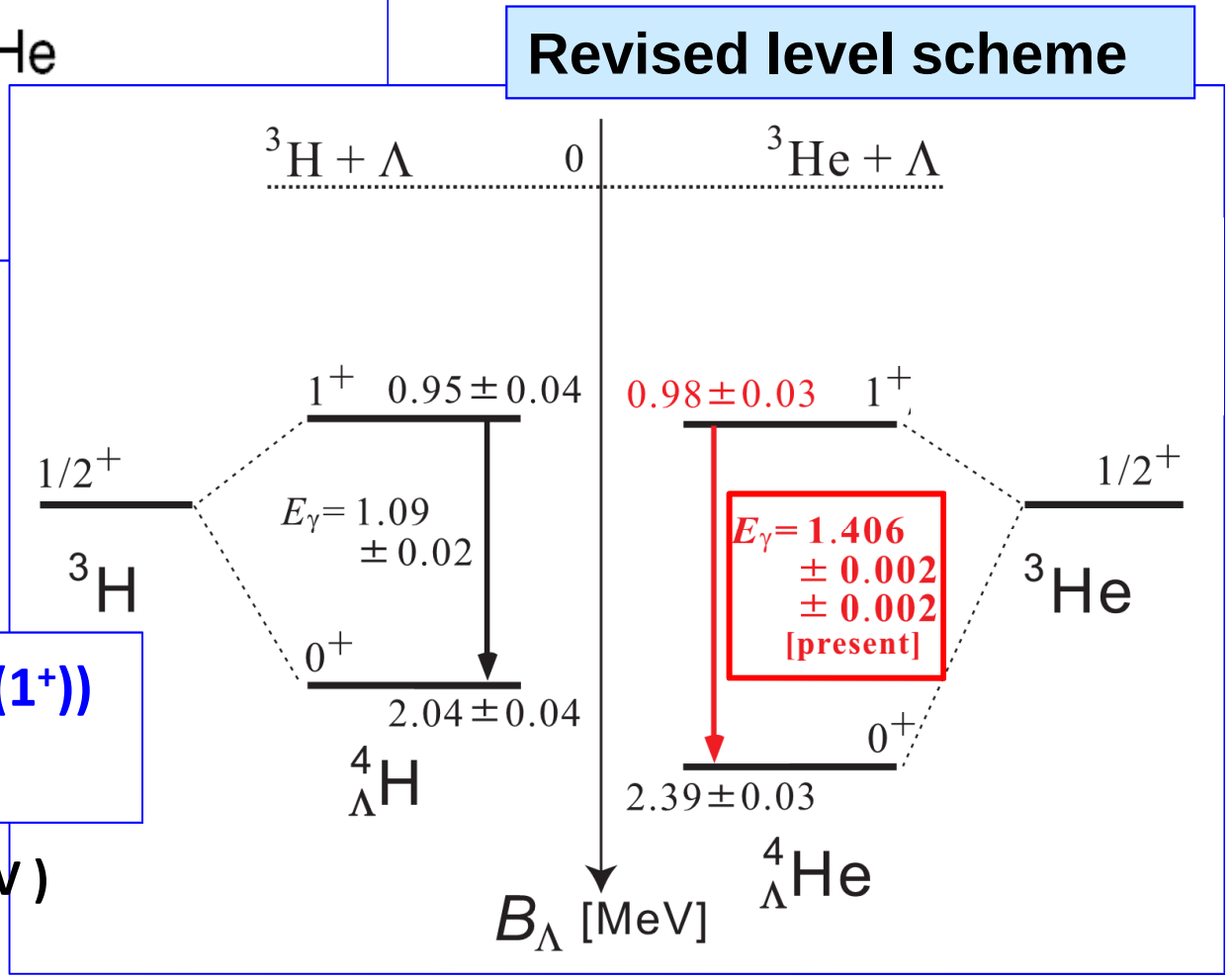
< Fit result >

Peak energy : 1406 ± 2(stat.) ± 2(syst.) keV

Counts : 95 ± 13 (7.3σ)

Revised 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

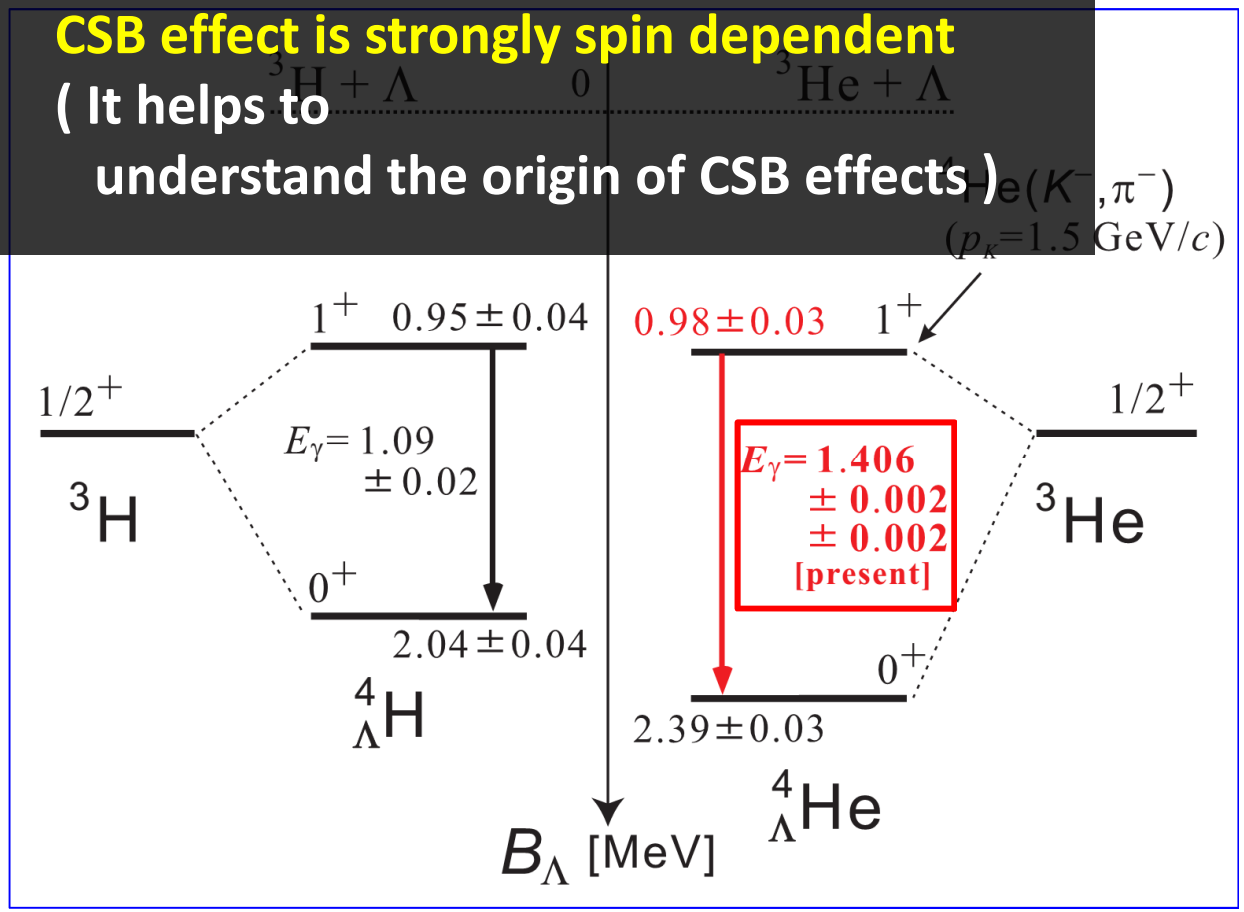
($\Delta B_\Lambda(0^+) = 0.35 \pm 0.05$ MeV)

Revised level scheme and our finding

- Compare with $E_\gamma(^4_\Lambda H) = 1.09$ MeV → large ΔE_γ value (= 320 keV)
  Existence of CSB was confirmed uniquely by gamma-ray data
- Combining emulsion data → $\Delta B_\Lambda(1^+) = 0.03 \pm 0.05$ MeV
  (while $\Delta B_\Lambda(0^+) = 0.35 \pm 0.05$ MeV)

$$\frac{\Delta B_\Lambda(0^+)}{\Delta B_\Lambda(1^+)} = \frac{0.35\ \text{MeV}}{0.03\ \text{MeV}} = 12$$

CSB effect is strongly spin dependent
(It helps to understand the origin of CSB effects)



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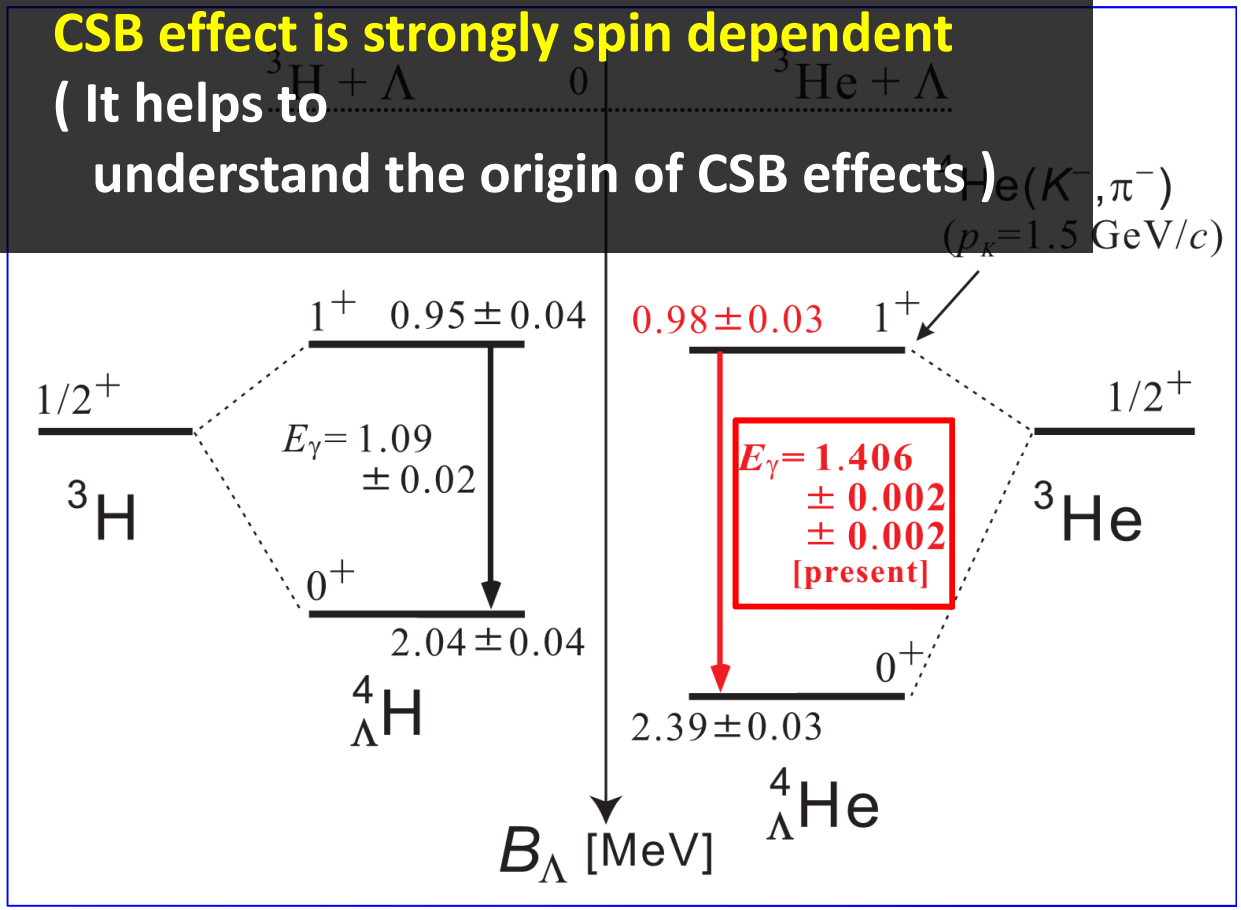

Theoretical calculation

A. Gal, Phys. Lett. B 744, 352 (2015).

Central ΛN-ΣN mixing force

	Exp.	Calc.
$\Delta B_\Lambda(1^+)$	0.03(5)	0.04
$\Delta B_\Lambda(0^+)$	0.35(5)	0.25

(unit : MeV)

Summary

γ-ray spectroscopy of $^{4}_{\Lambda}$He was performed.

- **Excitation energy of $^{4}_{\Lambda}$He(1^{+})**

  = 1.406 ± 0.002(stat.) ±0.002(syst.) MeV

  - **Existence of CSB was confirmed**

    uniquely by γ-ray spectroscopy (compared with $E_{\gamma}(^{4}_{\Lambda}H)$)

  - **CSB effect is strongly spin-dependent**

    (combined with emulsion data)

$$\frac{\Delta B_{\Lambda}(0^{+})}{\Delta B_{\Lambda}(1^{+})} = \frac{0.35\ \mathrm{MeV}}{0.03\ \mathrm{MeV}} = 12$$

Our updated data invite renewed interests and further studies on CSB effects in ΛN interaction.