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Prospect for the gamma-ray spectroscopy experiment of $^{4}_{\Lambda}\mathrm{H}$ with Hyperball system (J-PARC E63)

Chesu Seong

(Tohoku University)

J-PARC E63 collaboration

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   - Charge symmetry breaking between ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$
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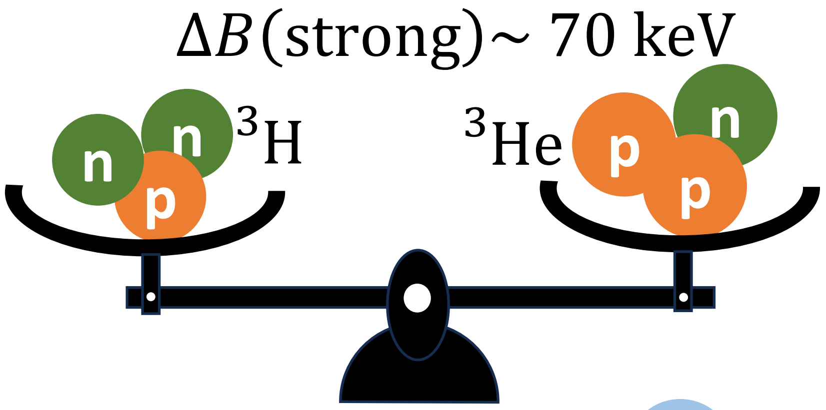
Contents

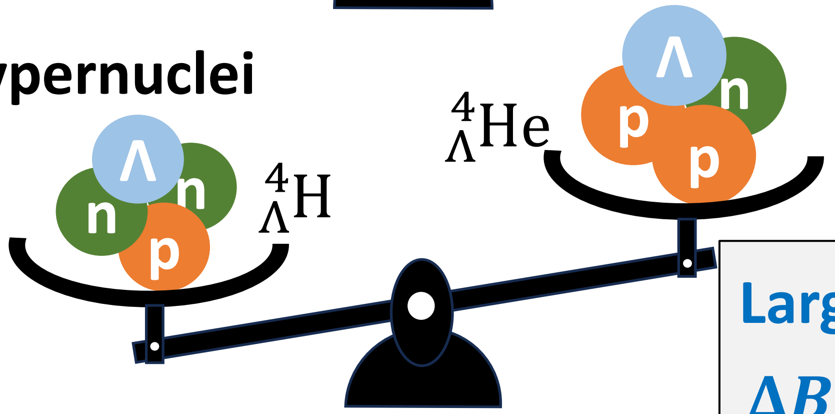
Charge symmetry breaking (CSB) between ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$

Properties of nuclei are invariant under the replacement between p and n (Charge Symmetry).
However, large CSB in A=4 hypernuclei was found, suggesting $\Lambda p \neq \Lambda n$.

Ordinary nuclei



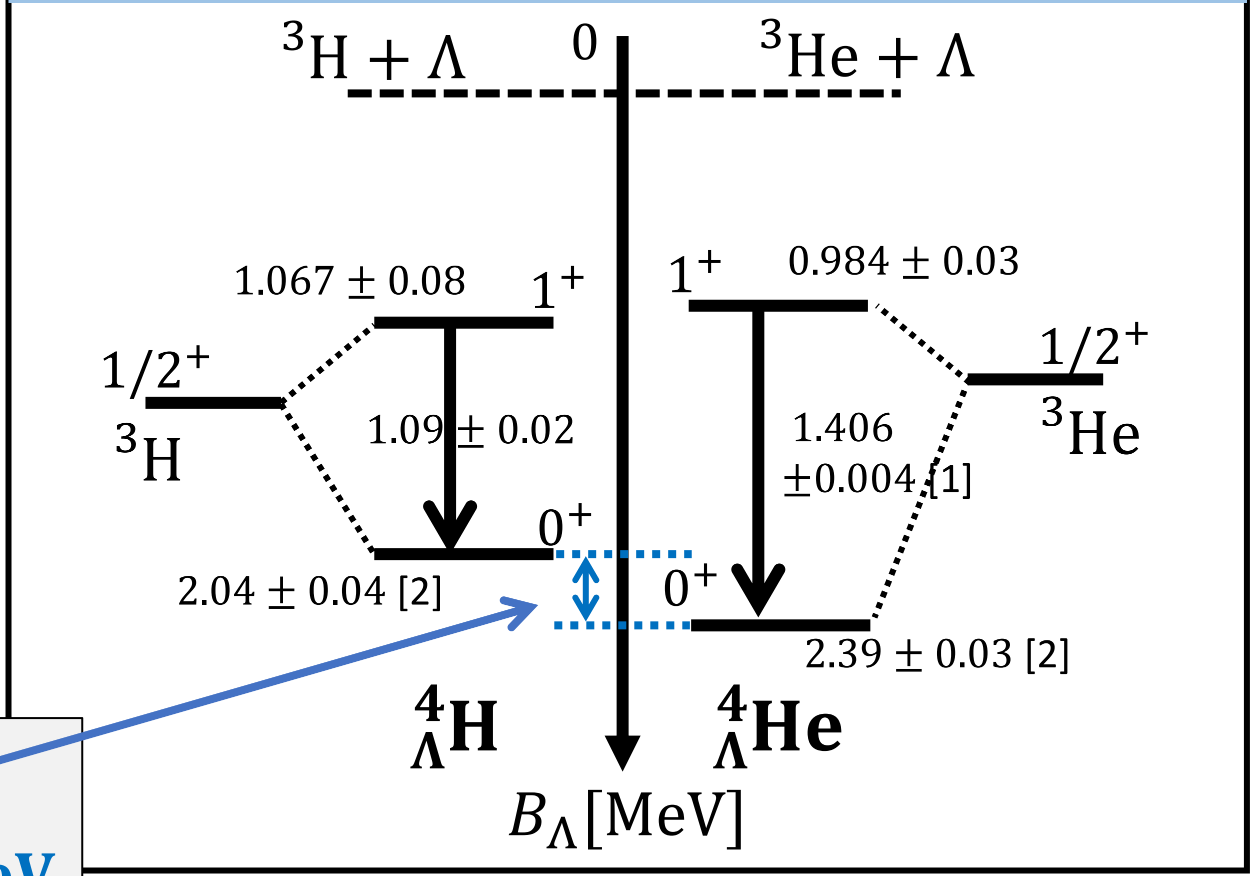
Hypernuclei



Large CSB

$\Delta B_{\Lambda} \sim 250$ keV

Level scheme of mirror hypernuclei ${}^{4}_{\Lambda}\mathrm{H}$ / ${}^{4}_{\Lambda}\mathrm{He}$



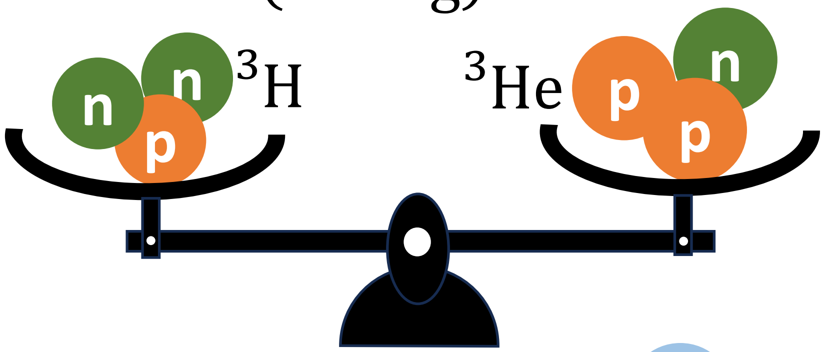
[1] T.O. Yamamoto et al., Phys. Rev. Lett., 115 (2015) 222501
[2] D.H. Davis, Nucle. Phys. Rev. A. 754 (2005) 3c

Charge symmetry breaking (CSB) between ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$

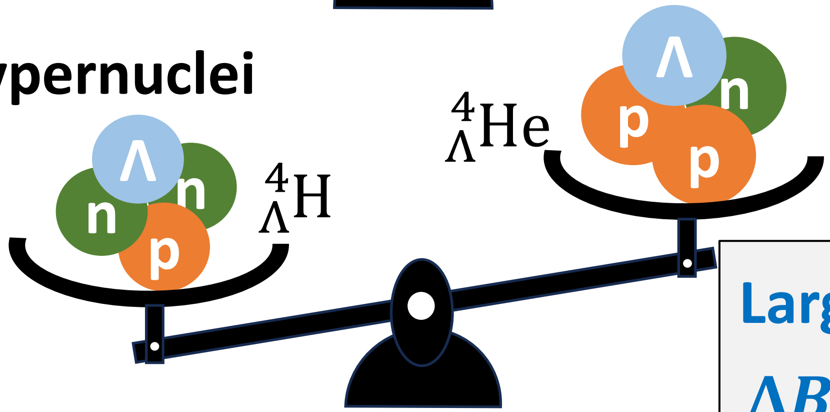
Properties of nuclei are invariant under the replacement between p and n (Charge Symmetry).
However, large CSB in A=4 hypernuclei was found, suggesting $\Lambda p \neq \Lambda n$.

Ordinary nuclei

$\Delta B(\mathrm{strong}) \sim 70\ \mathrm{keV}$



Hypernuclei



Large CSB

$\boldsymbol{\Delta B_{\Lambda} \sim 250\ \mathrm{keV}}$

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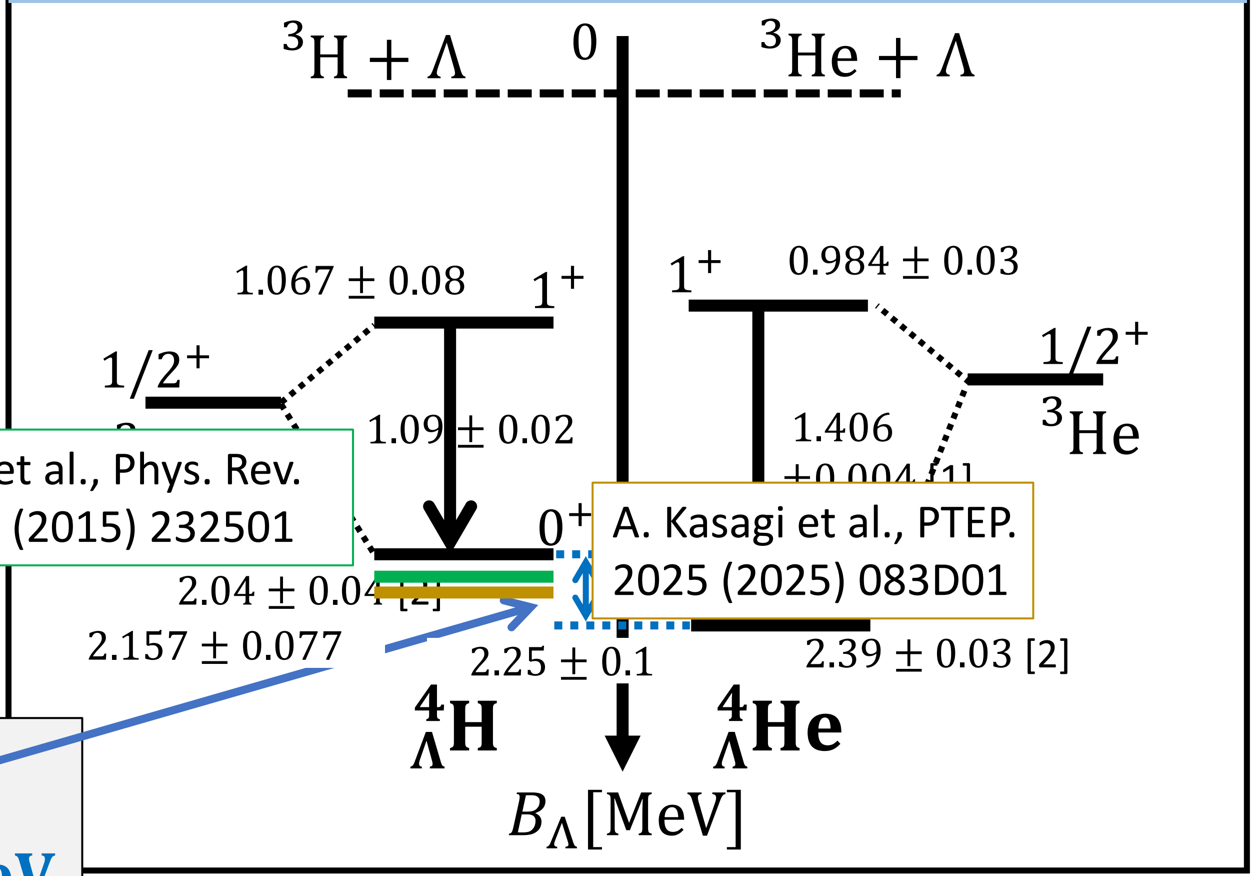


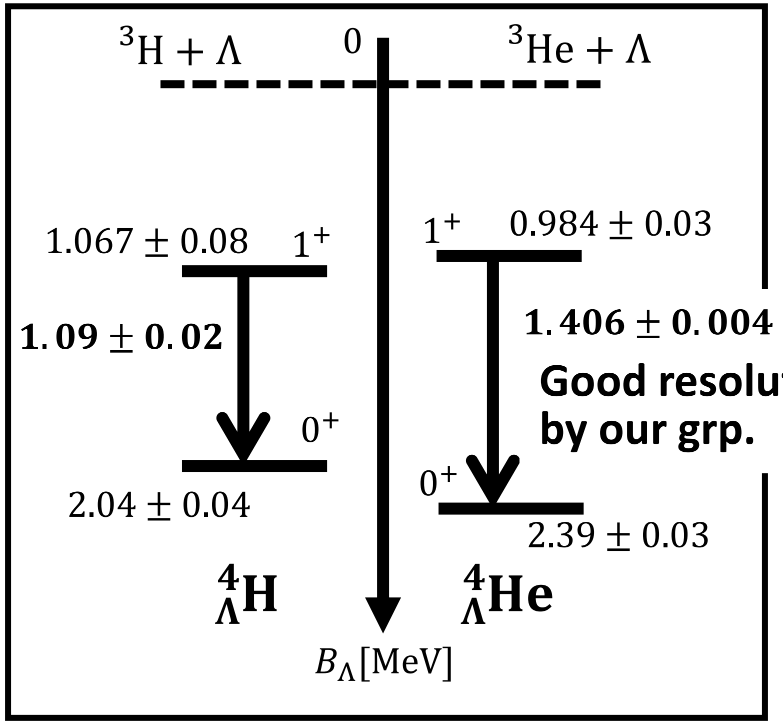
A. Esser et al., Phys. Rev. Lett. 114 (2015) 232501

A. Kasagi et al., PTEP. 2025 (2025) 083D01

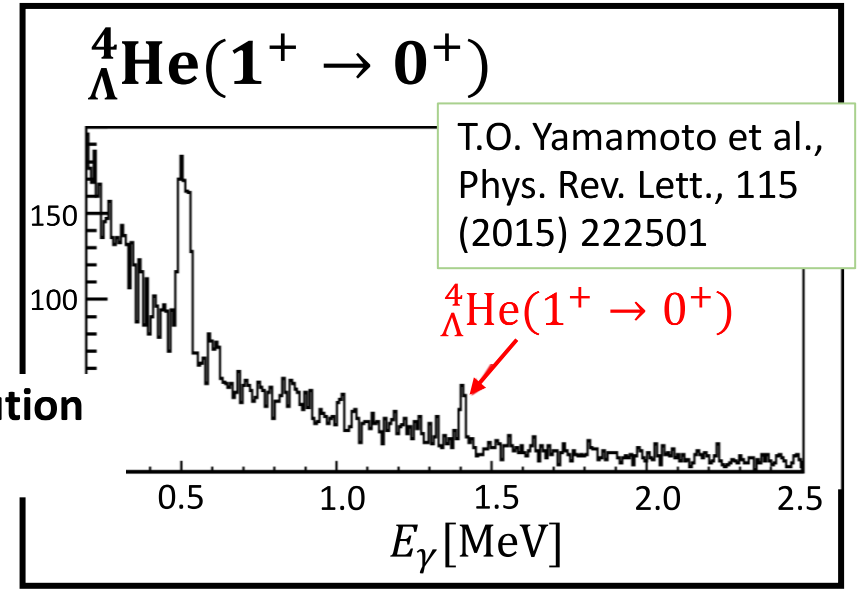
[1] T.O. Yamamoto et al., Phys. Rev. Lett., 115 (2015) 222501
[2] D.H. Davis, Nucle. Phys. Rev. A. 754 (2005) 3c

Previous experimental data

Importance of high-precision(<10 keV) γ-ray data for CSB study
Precise few-body calculation is possible.



Good resolution by our grp.



→ Confirmed presence of CSB

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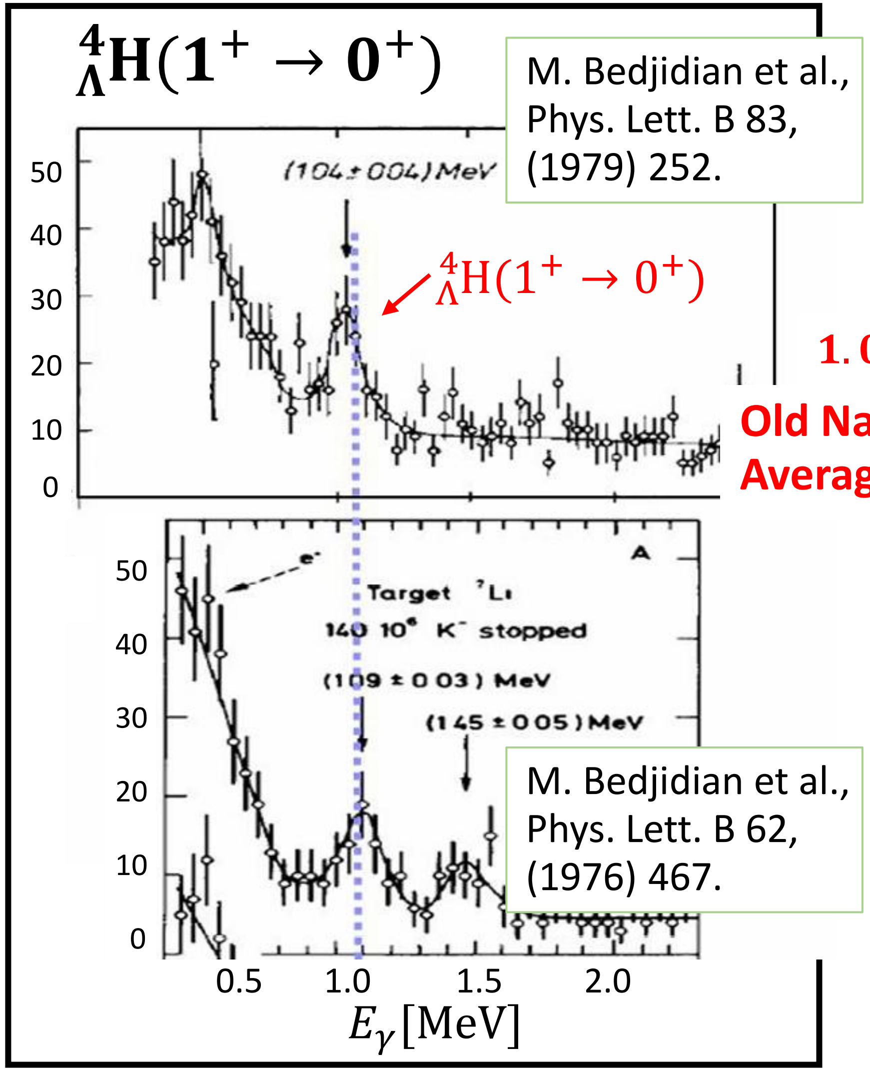

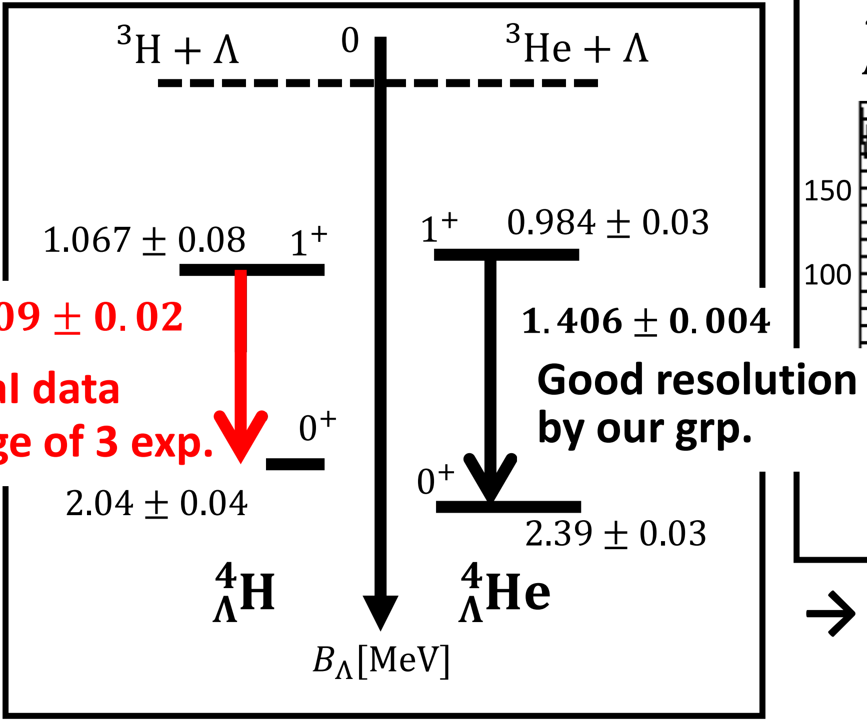

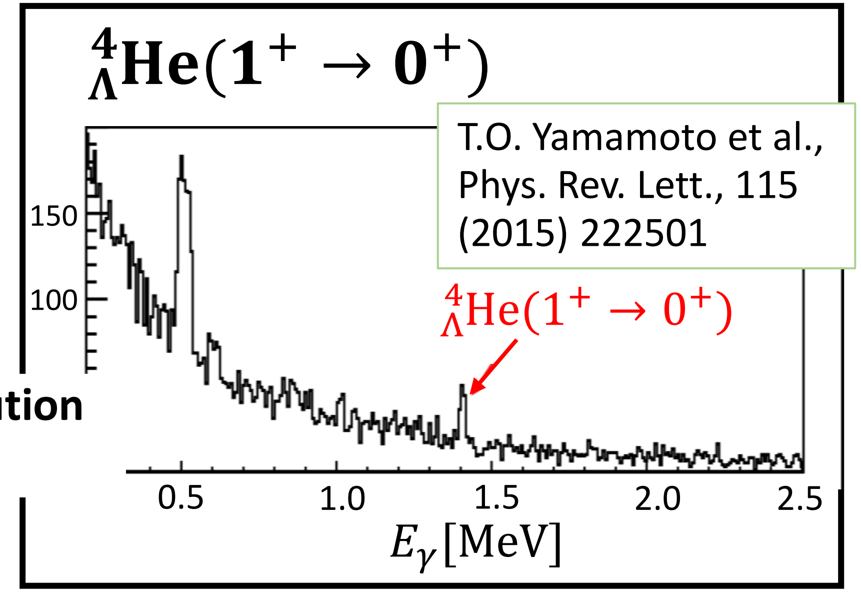

→ **Confirmed presence of CSB**

Previous experimental data

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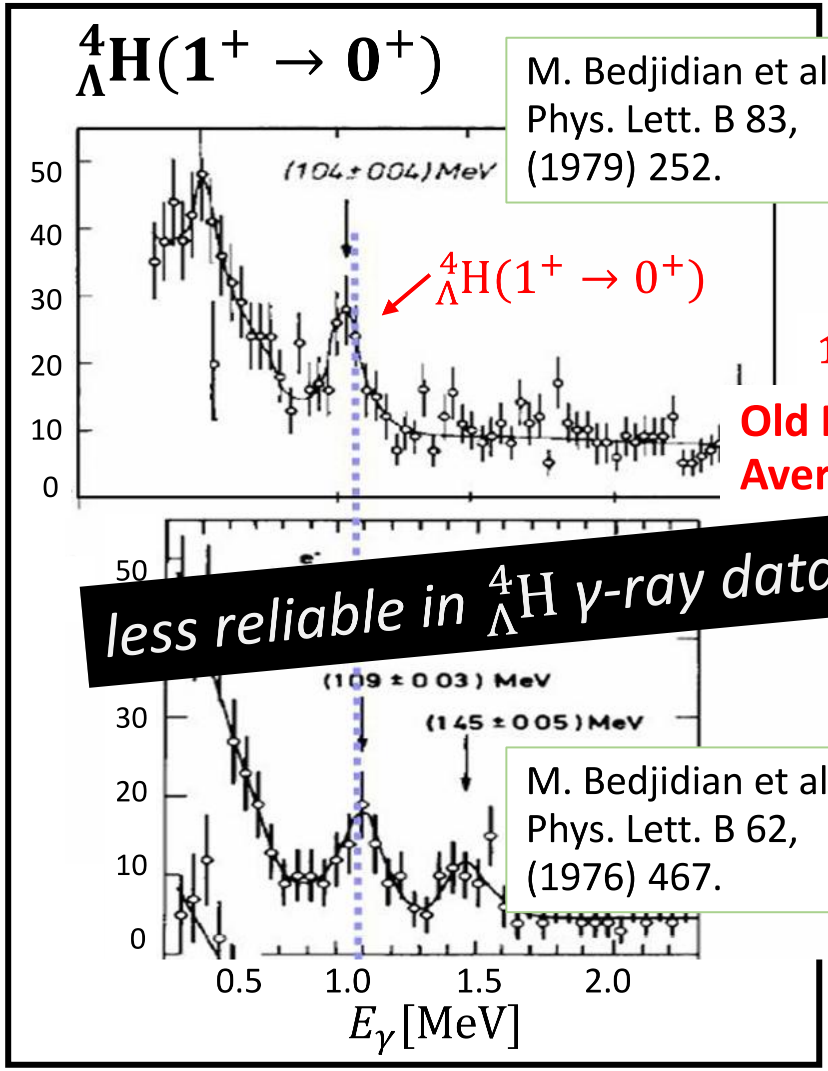
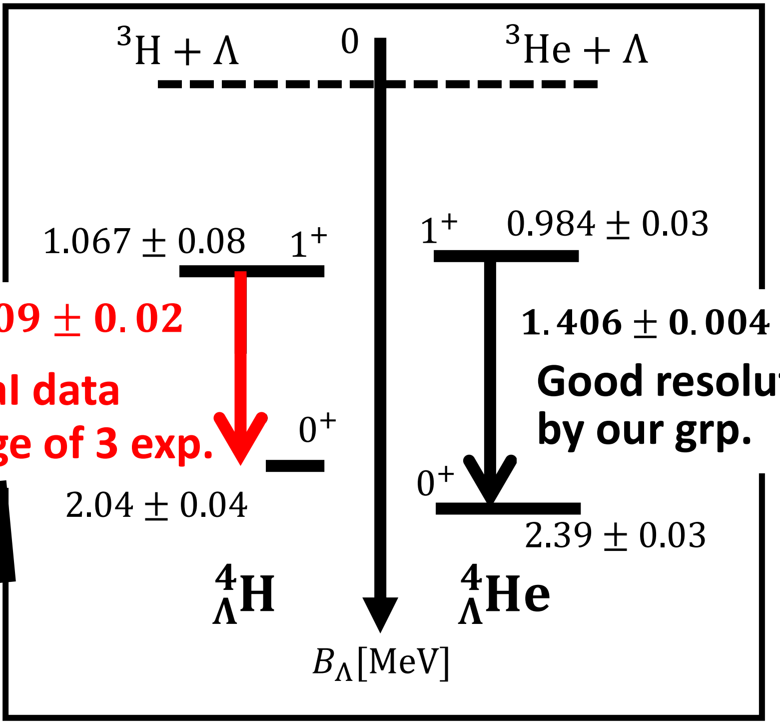


less reliable in $^{4}_{\Lambda}\mathrm{H}$ γ-ray data

Old NaI data
Average of 3 exp.



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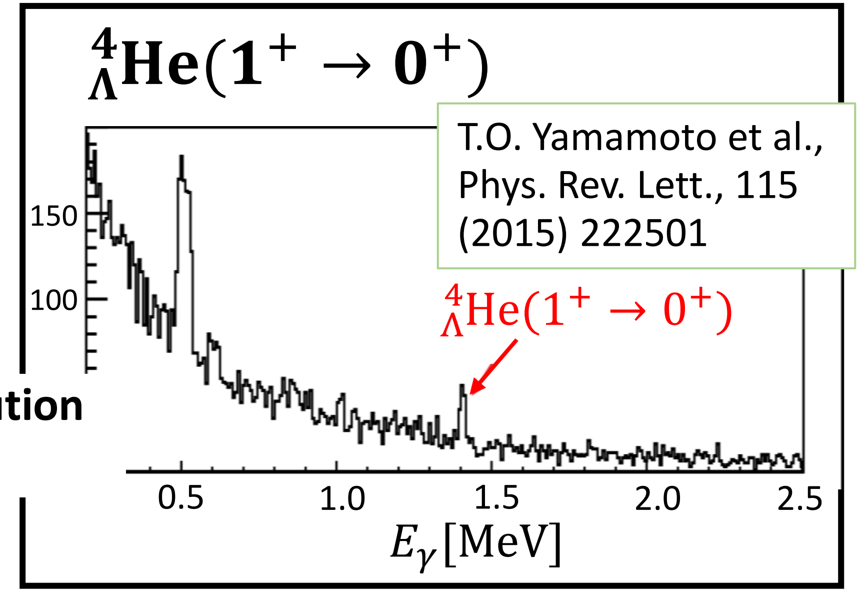


→ Confirmed presence of CSB

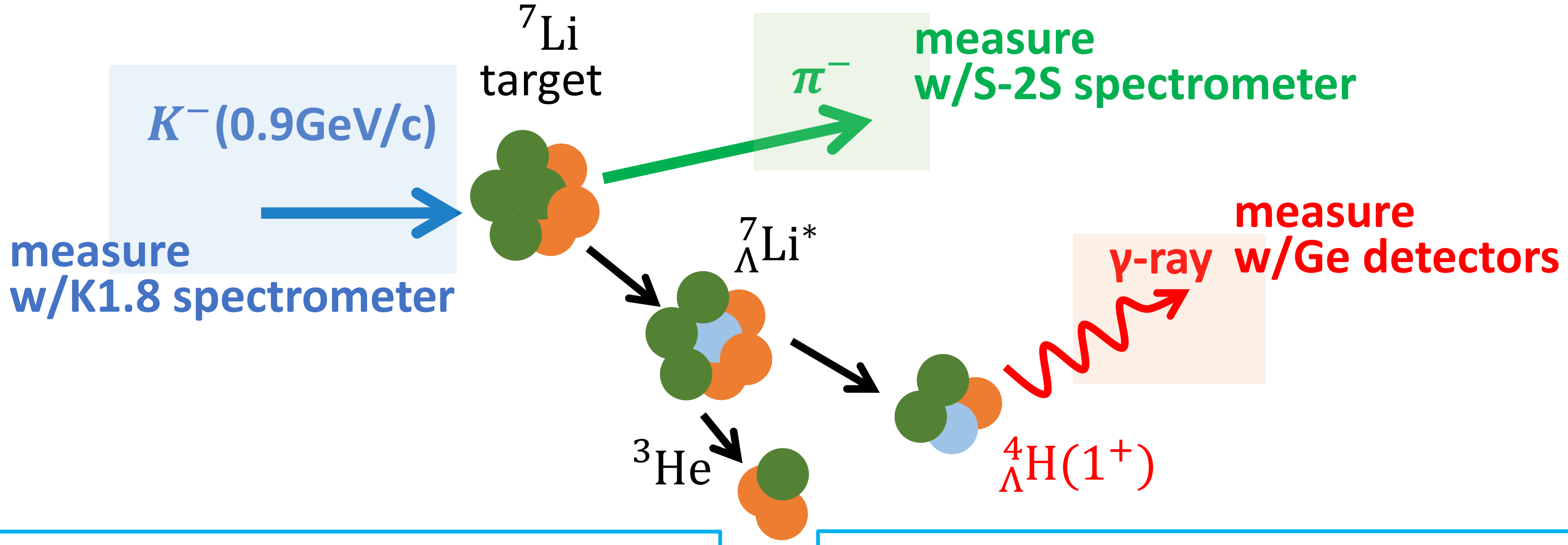
We plan (J-PARC E63)

a precise measurement of γ-ray from $^{4}_{\Lambda}\mathrm{H}(1^+ \to 0^+)$

by using a high-resolution Ge detector array at J-PARC

Contents

Experimental procedure and setup



Previous experiments

→ Stopped K^- on Li

- Large recoil momentum(~250 MeV/*c*)
  - large doppler broadening

→ NaI Counters

- Bad energy resolution
  ~ 100 keV(FWHM) at 1 MeV γ

Our experiment

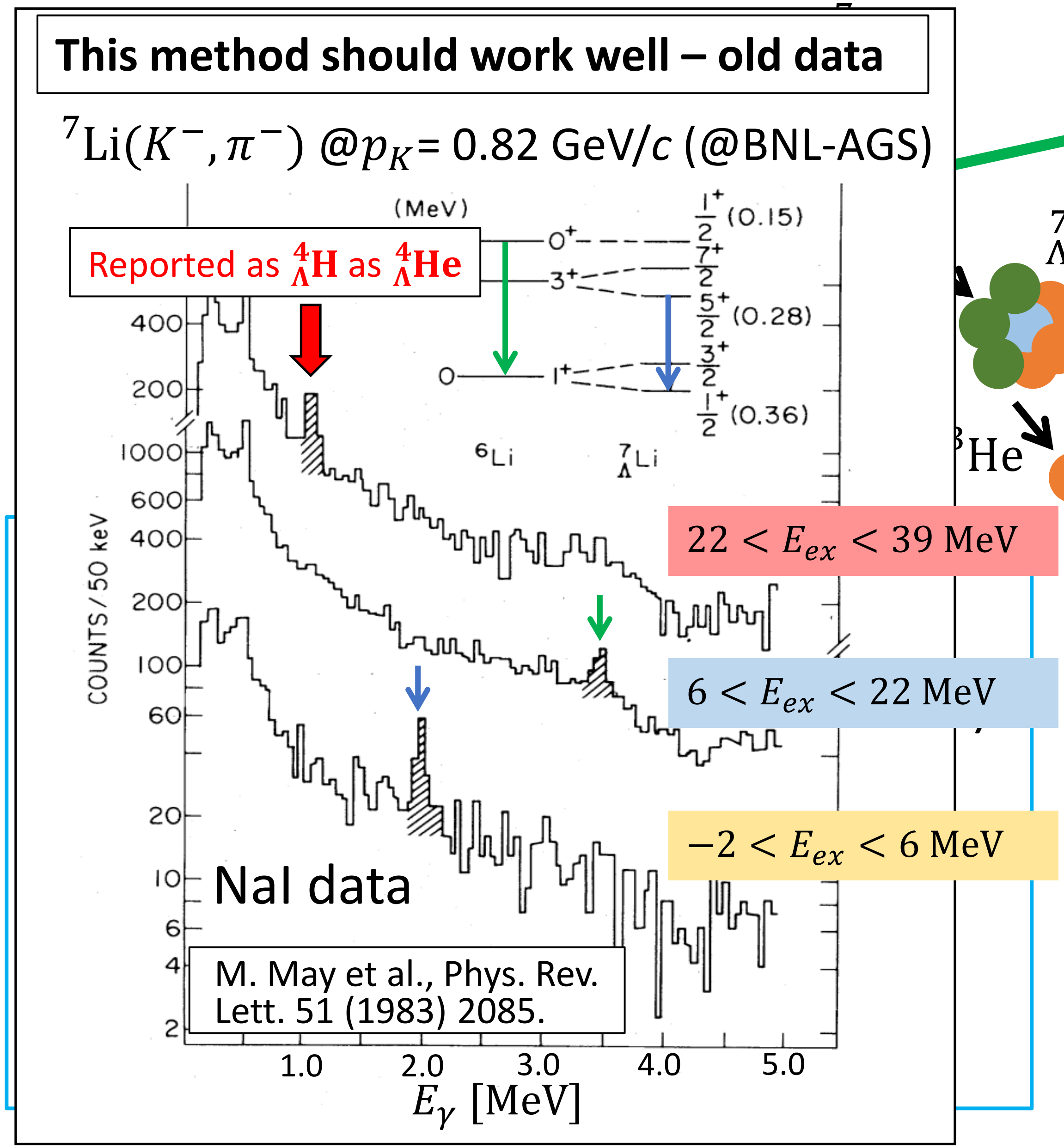
→ Inflight (K^-, π^-) by 0.9 GeV/*c* K^-

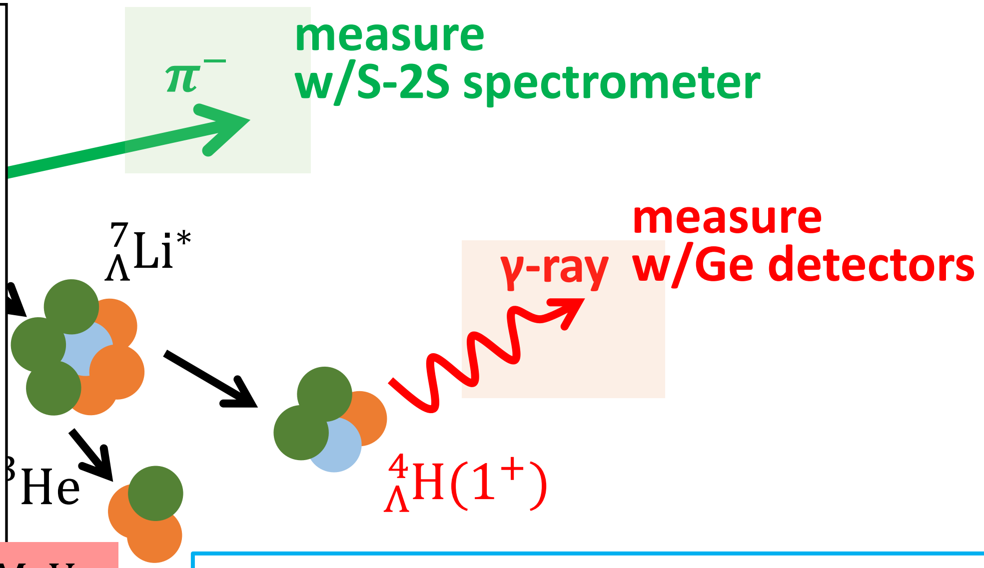
- Small recoil momentum(~70 MeV/*c*)
  - small doppler broadening

→ Ge detectors

- Good energy resolution
  ~ 2 keV(FWHM) at 1 MeV γ

Experimental procedure and setup





Our experiment

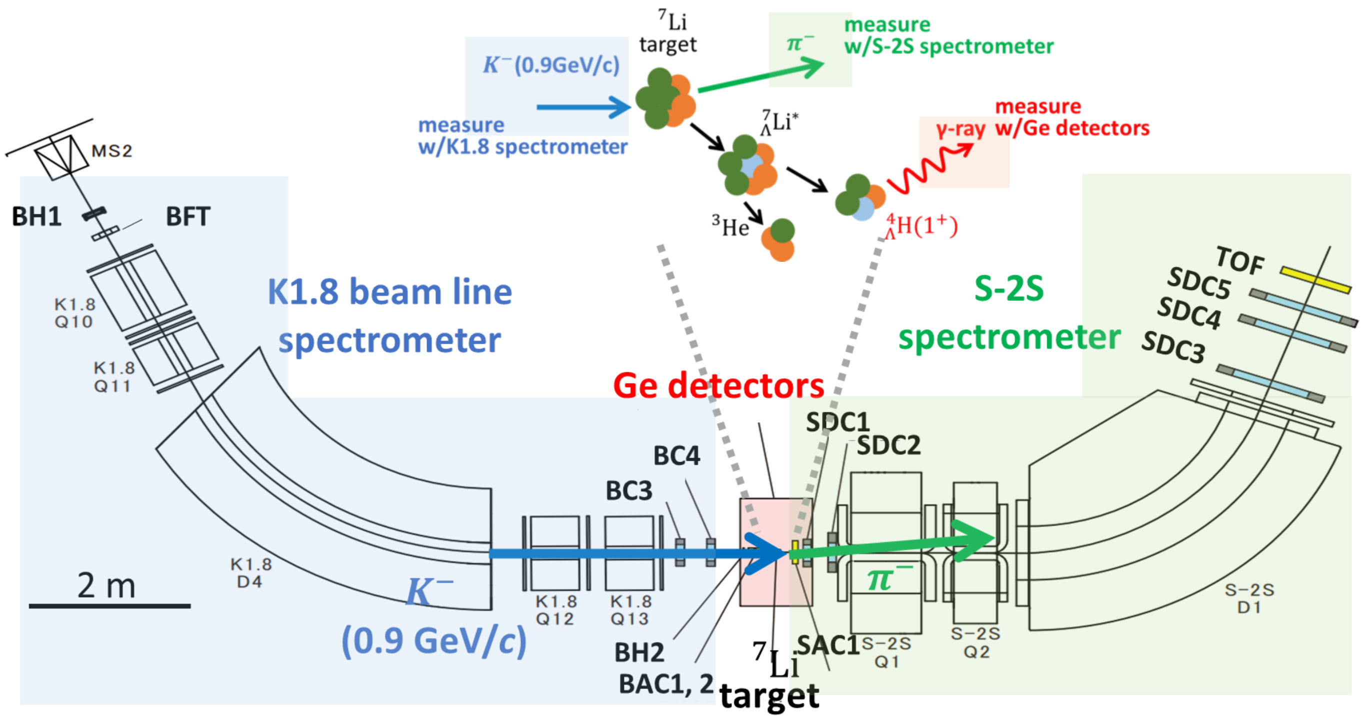
→ **Inflight (K^-,π^-) by 0.9 GeV/c K^-**
- Small recoil momentum(~70 MeV/c)
  - small doppler broadening

→ **Ge detectors**
- Good energy resolution
  ~ 2 keV(FWHM) at 1 MeV γ

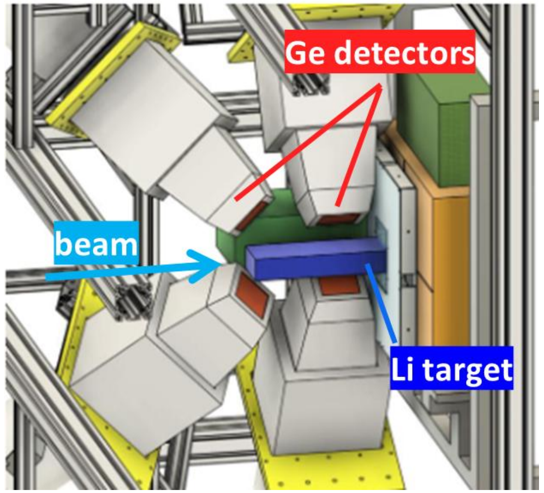
Tohoku Univ. C. Seong

Experimental setup at J-PARC K1.8 beam line

We revised the beam line as K1.1 -> K1.8



Ge detector array (half)



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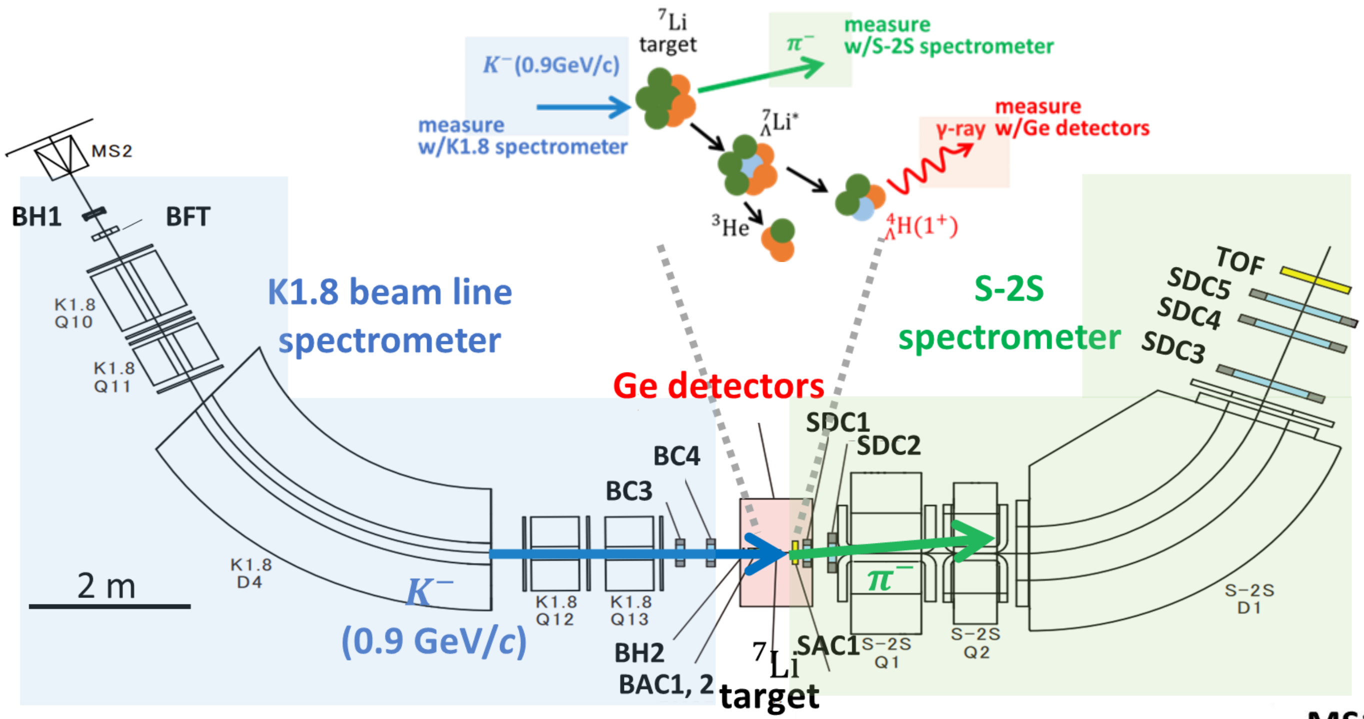

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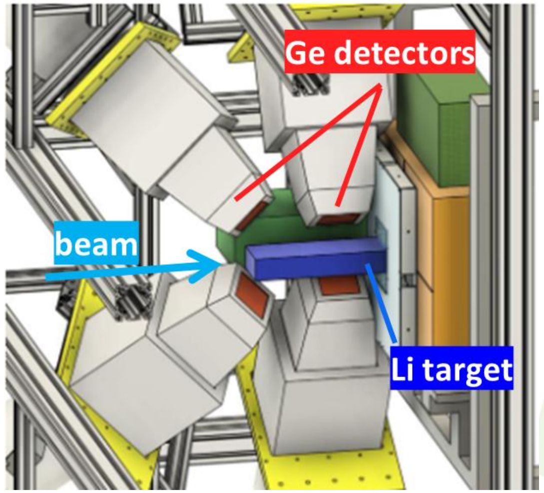

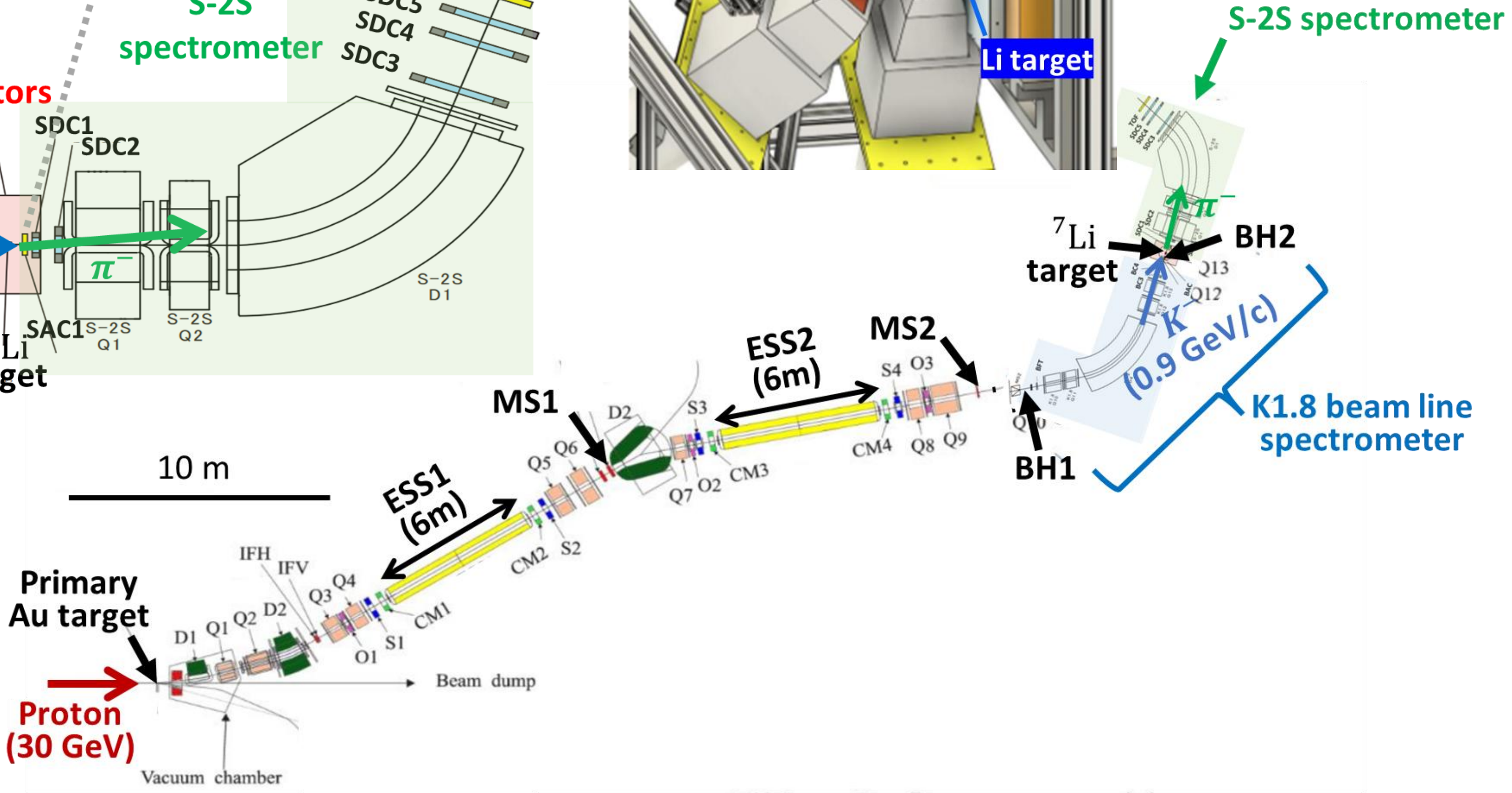

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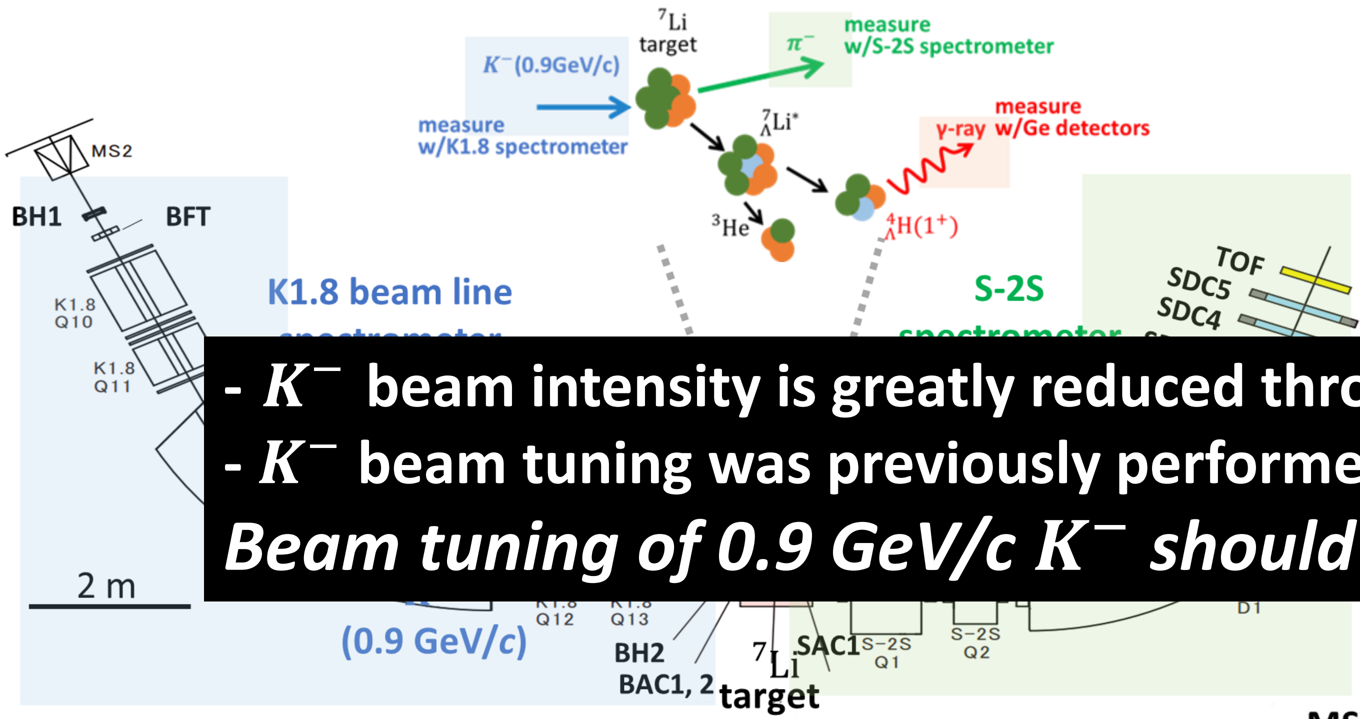

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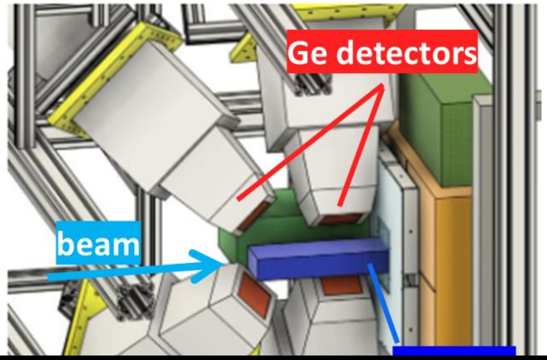
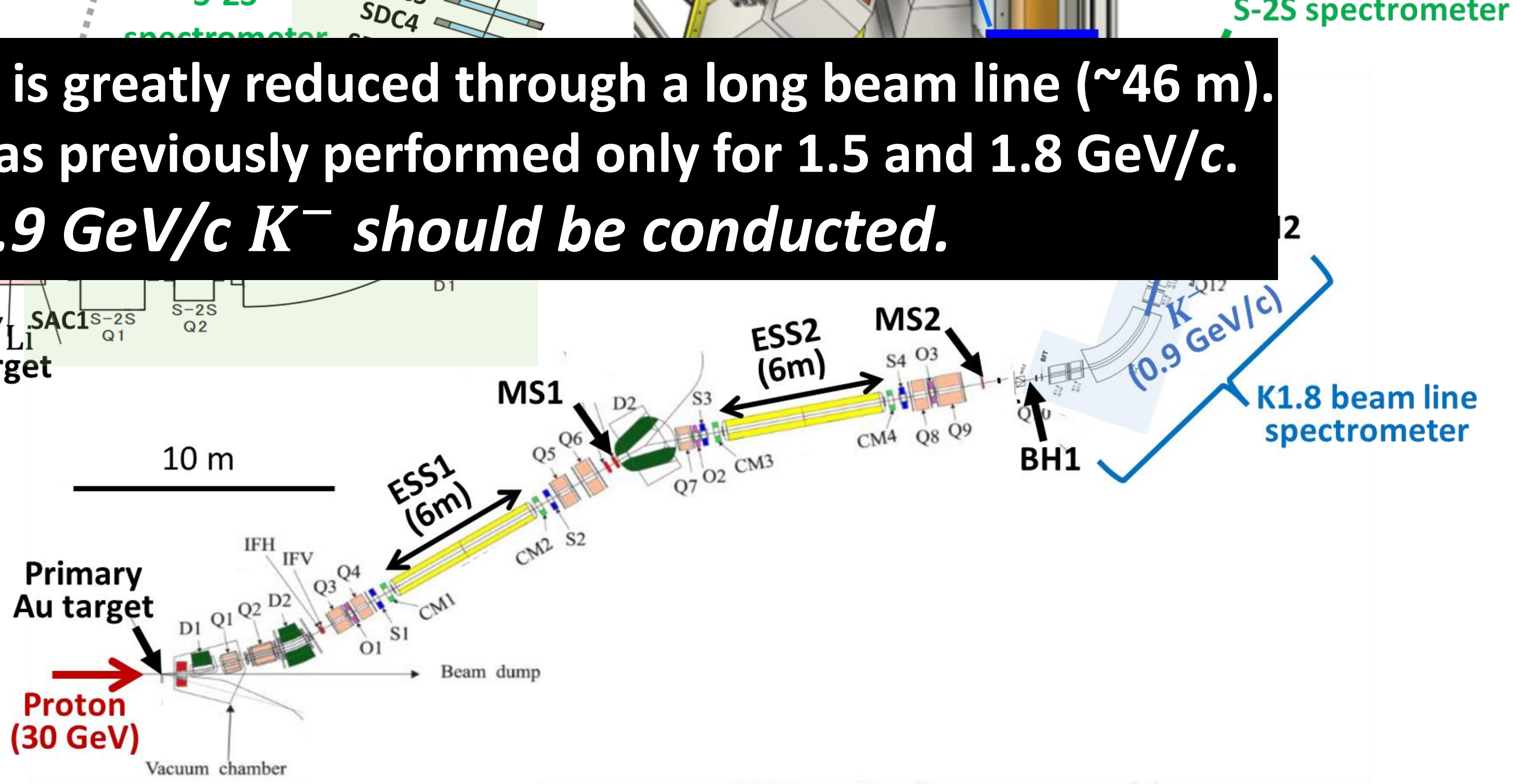


- K^- beam intensity is greatly reduced through a long beam line (~46 m).
- K^- beam tuning was previously performed only for 1.5 and 1.8 GeV/c.

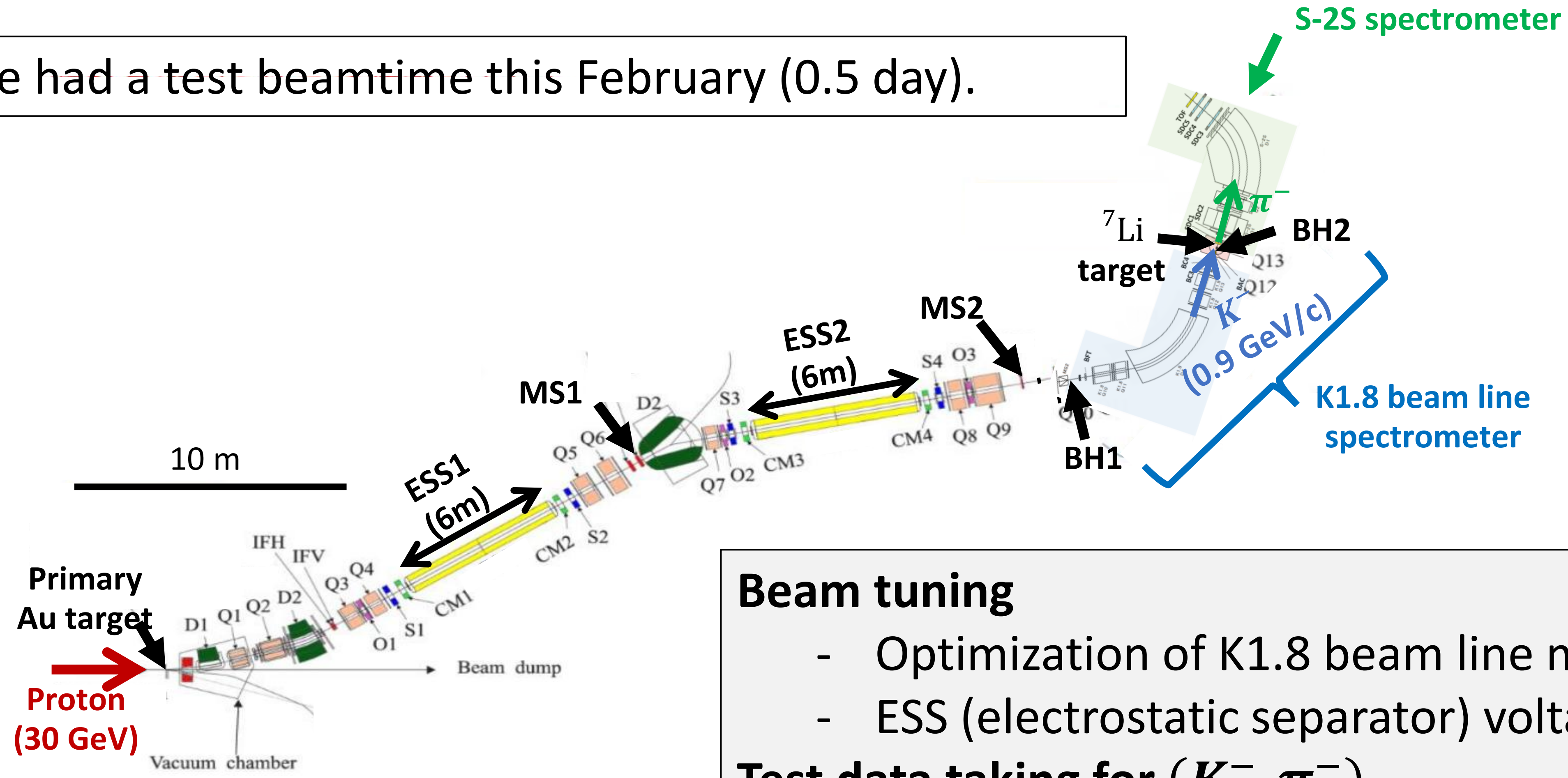
Beam tuning of 0.9 GeV/c K^- should be conducted.



Contents

Test with 0.9 GeV/c K^- beam

We had a test beamtime this February (0.5 day).



Beam tuning

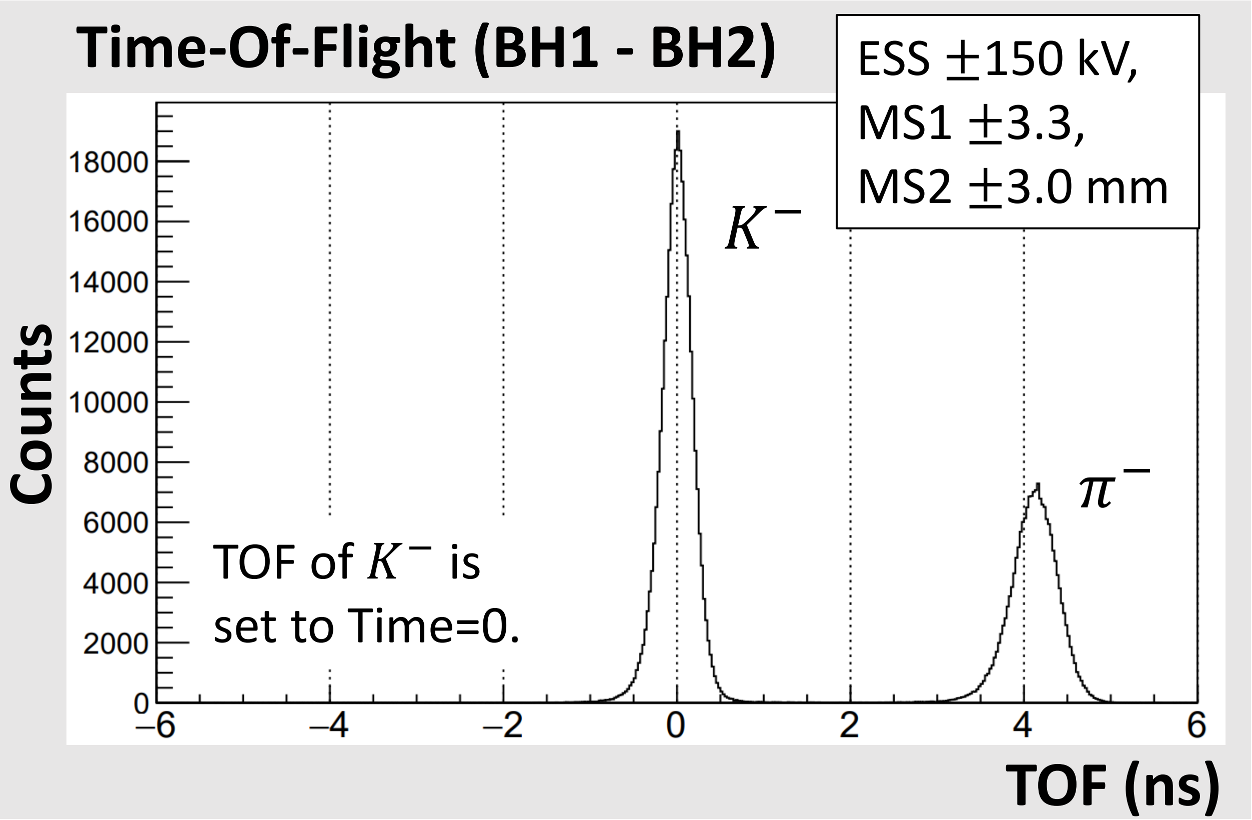
- Optimization of K1.8 beam line magnet currents
- ESS (electrostatic separator) voltage tuning

Test data taking for (K^-, π^-)

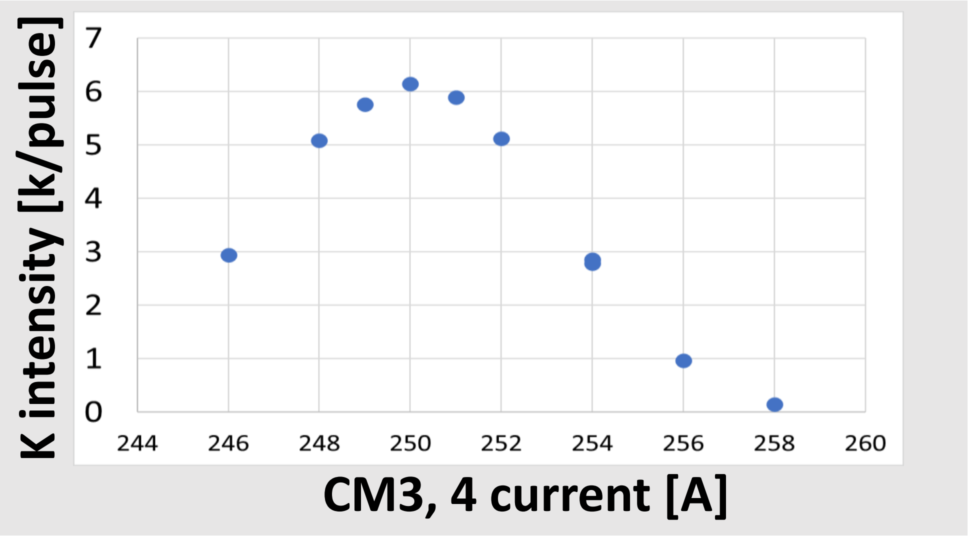
- With a $(\mathrm{CH})_n$ target ($\sim 9\ \mathrm{g/cm^2}$)
- Without target

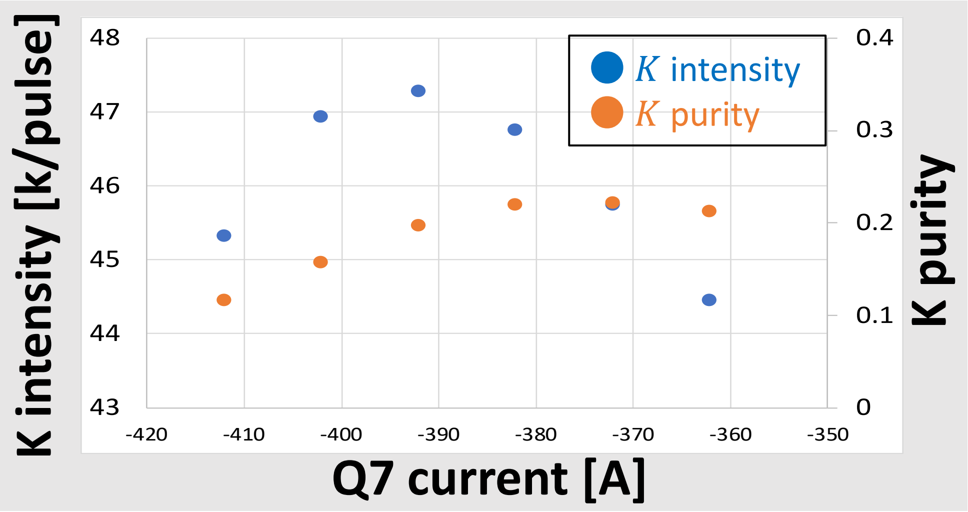
Beam line tuning for 0.9 GeV/c K^- at K1.8

0.9 GeV/c K^- and π^- were identified by TOF between BH1 - BH2 (time difference ~4.4 ns).



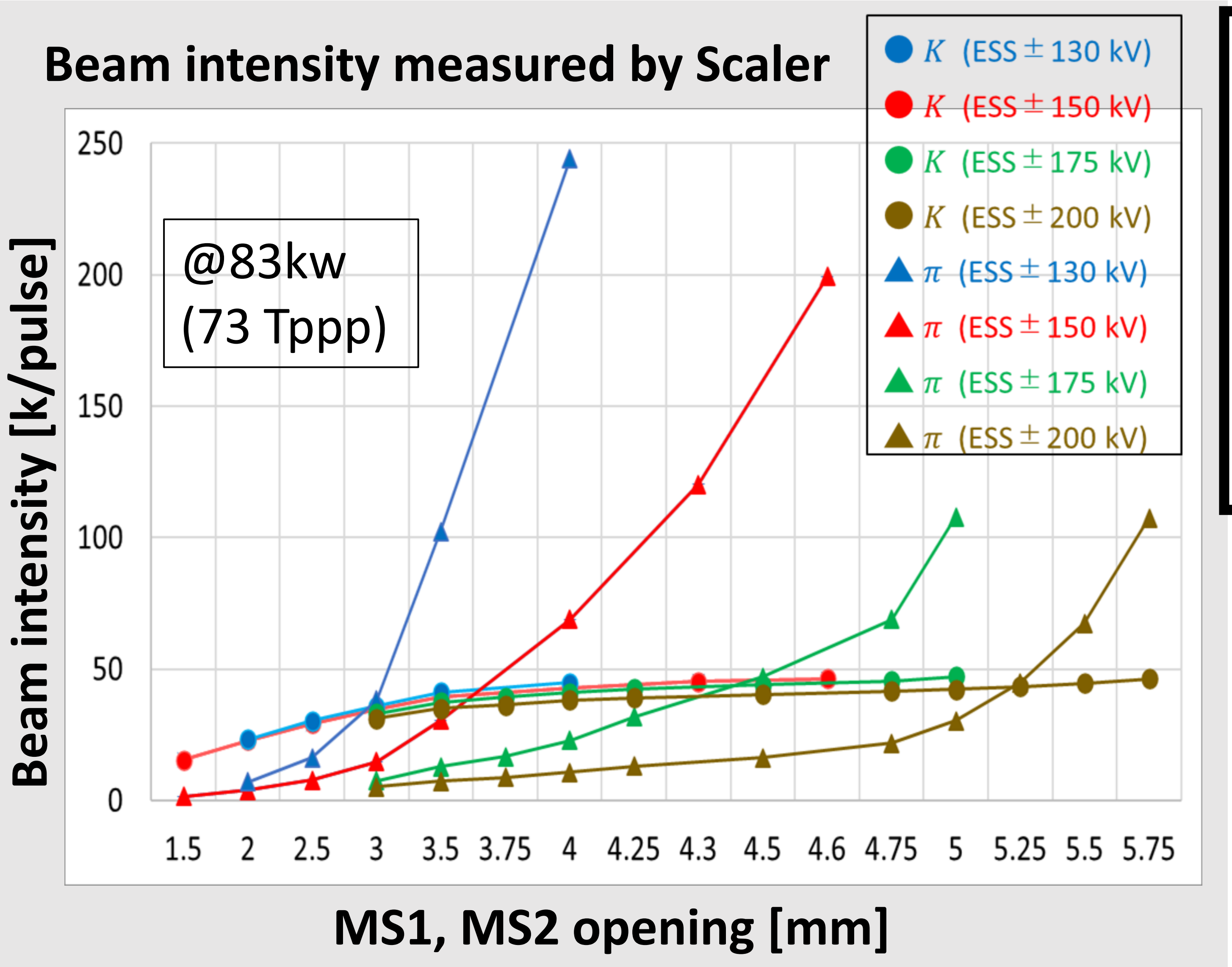
Magnet scan → CM1-4, D2, D3, D4, Q1, Q2, Q3, Q4, Q7 (12/27 magnets)

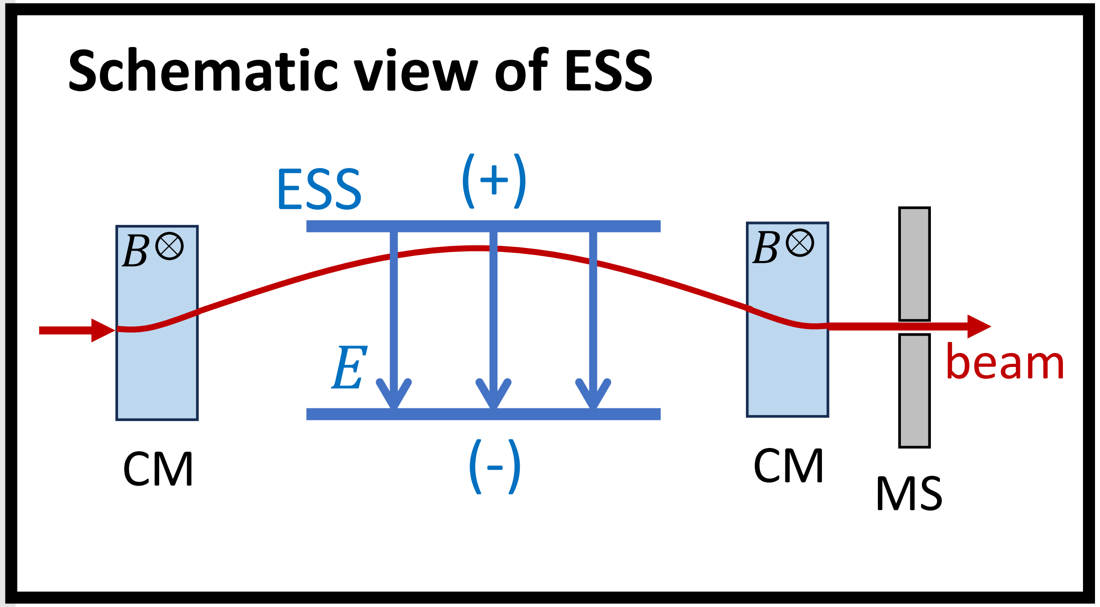




Results of the beam line tuning

Electrostatic separator (ESS) voltage tuning → 130 kV, 150 kV, 175 kV, 200 kV

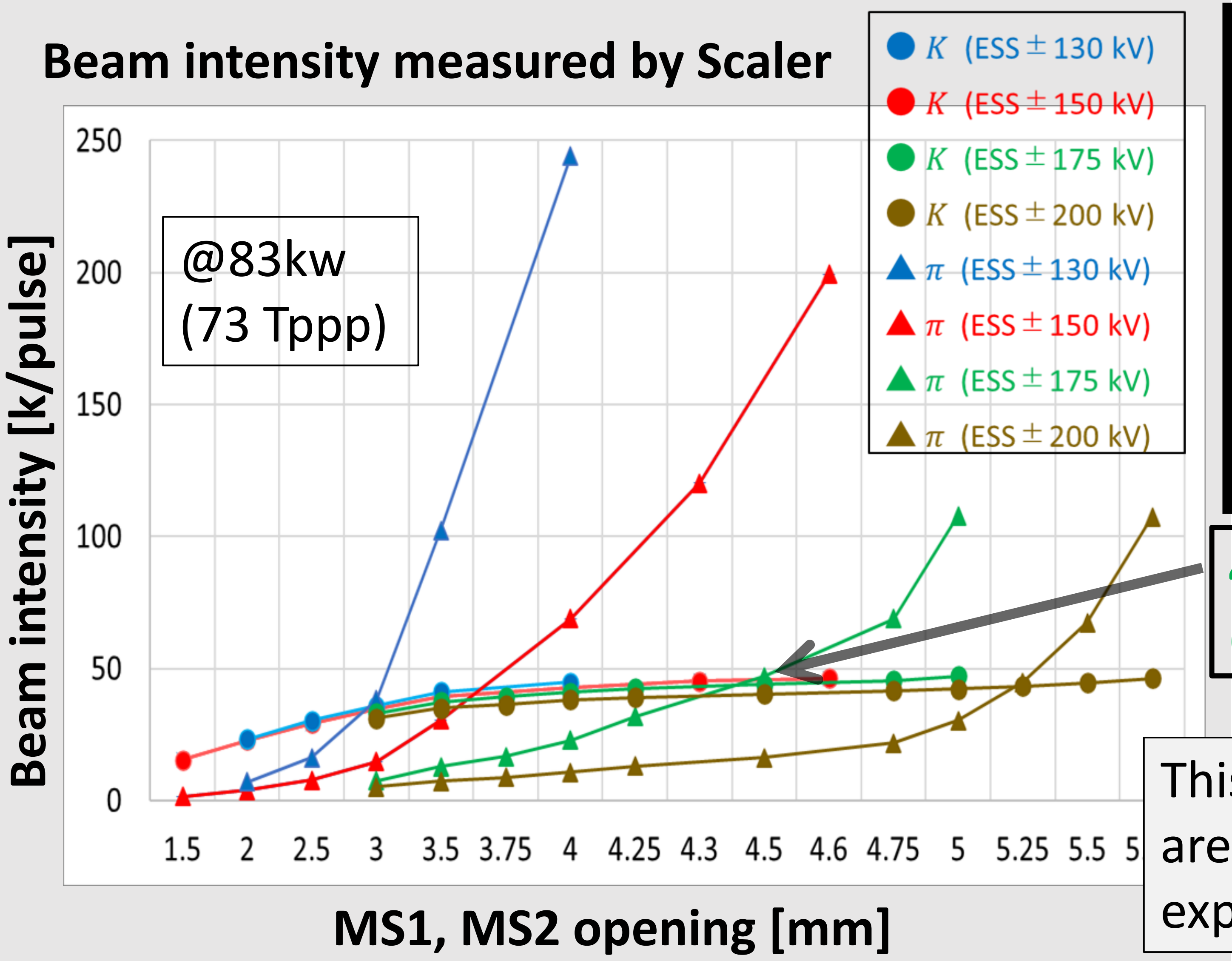




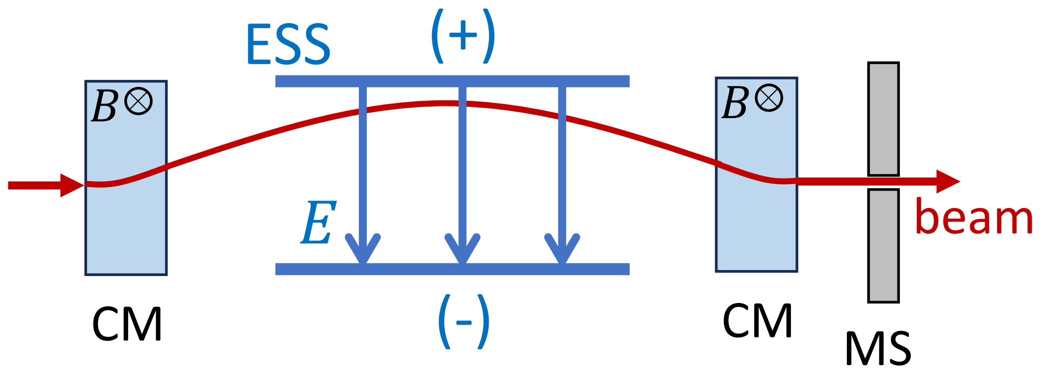
Results of the beam line tuning

Electrostatic separator (ESS) voltage tuning → 130 kV, 150 kV, 175 kV, 200 kV

Beam intensity measured by Scaler



Schematic view of ESS



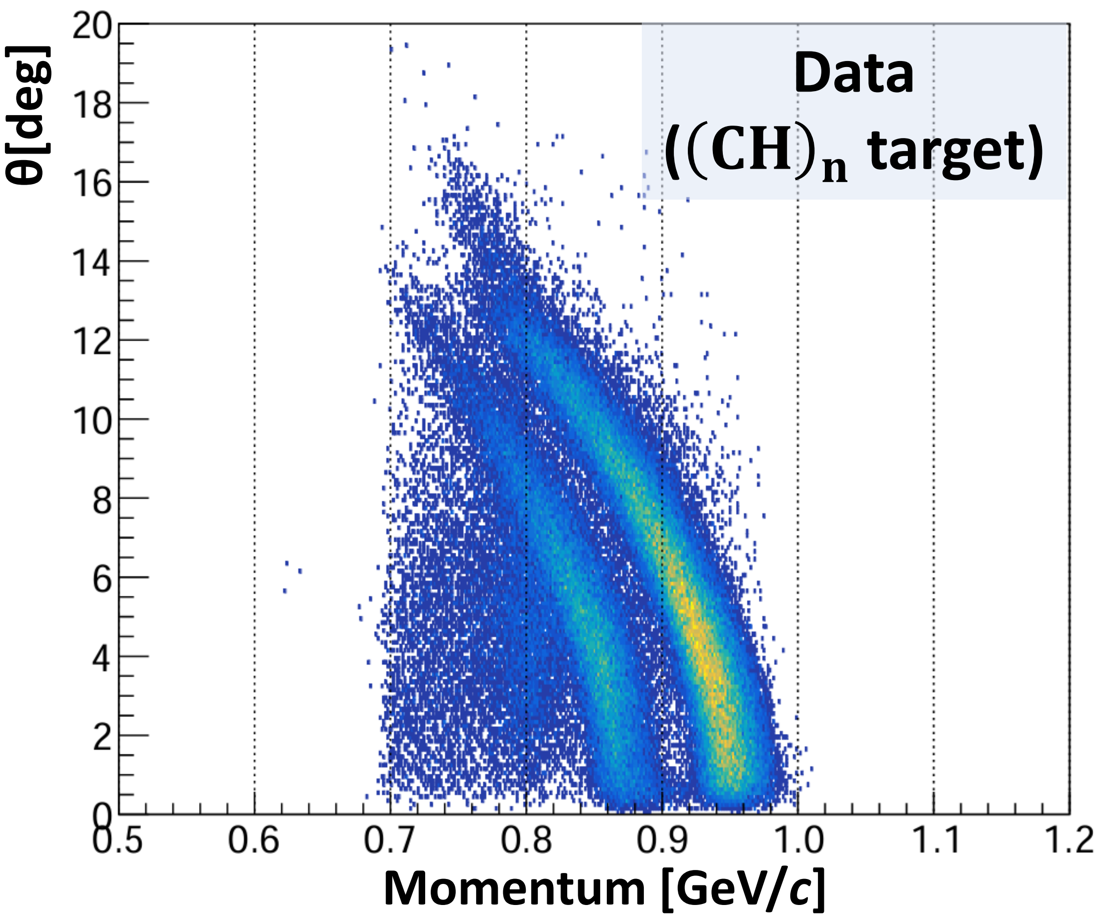
44 k/pulse (K/pi ratio ~1) @ESS 175kV

This K^- intensity and K/π ratio at 0.9 GeV/c are sufficient for various hypernuclear experiments.

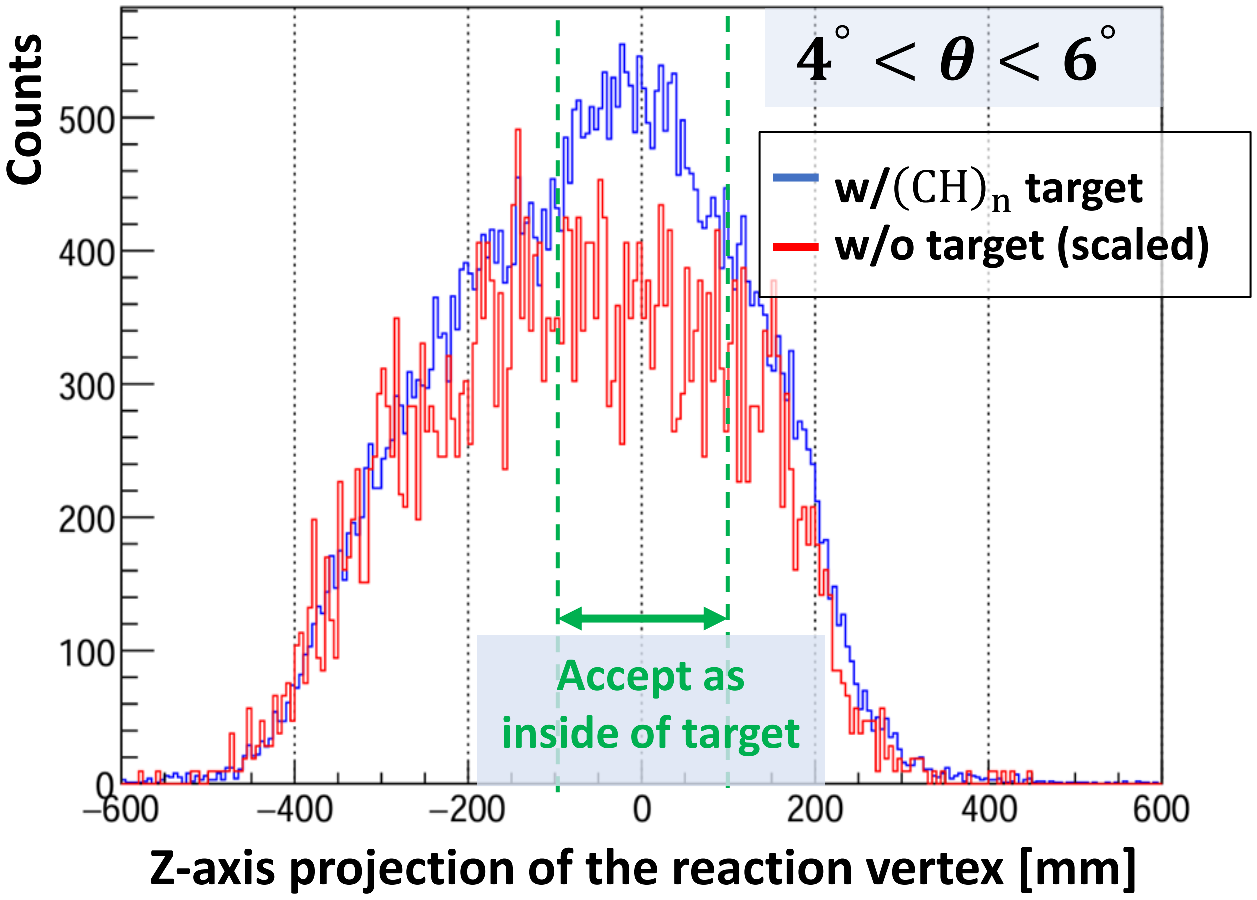
Contents

Reconstruction of (K^-, π^-) reaction

Correlation between p_{scat} and θ



Reaction vertex



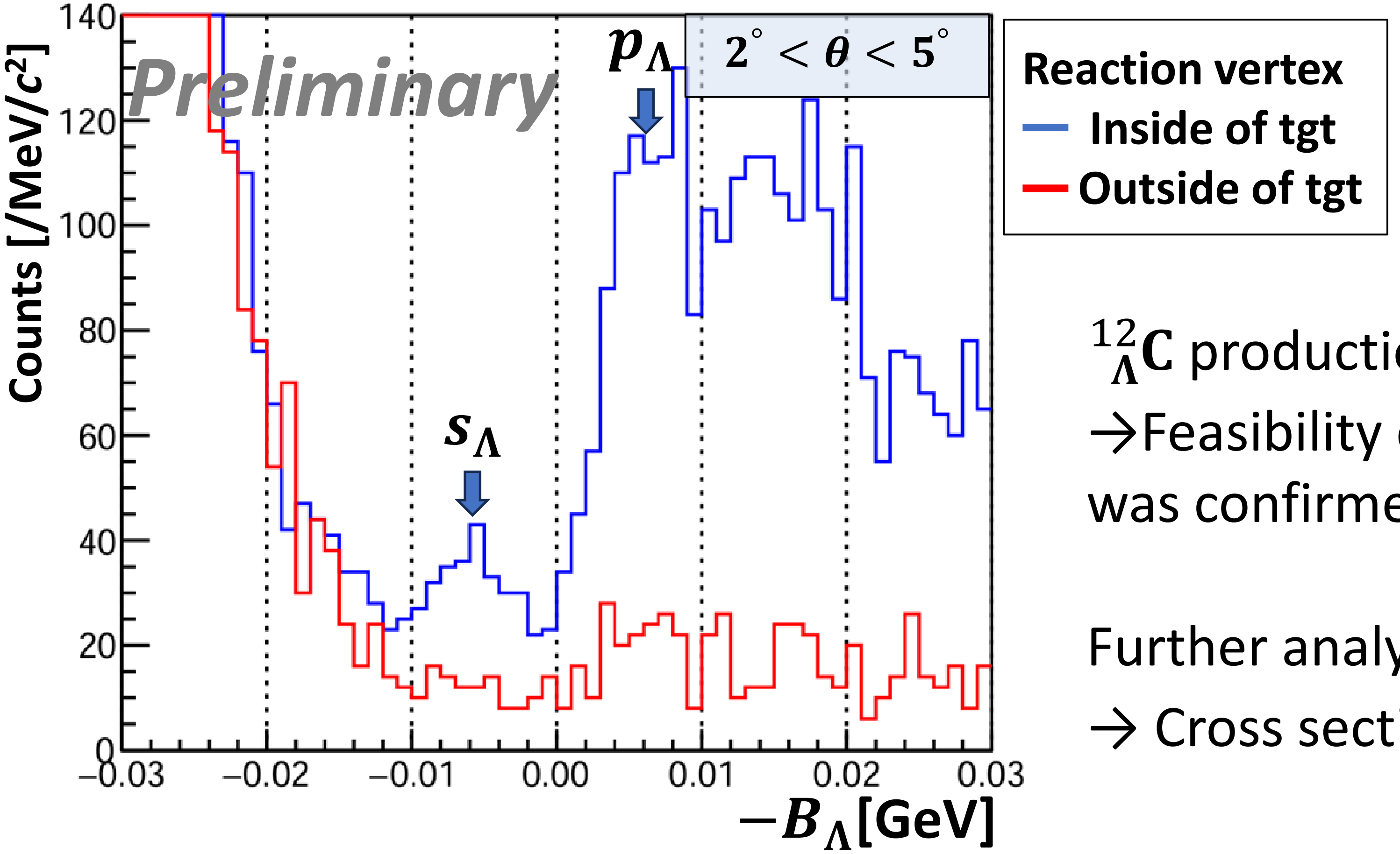
(K^-, π^-) reaction events are selected.

Missing mass spectrum of $^{12}\mathrm{C}(K^-,\pi^-)$ reaction

Λ Binding Energy ($-B_\Lambda$)

$$-B_\Lambda = M_{Hyp} - (M_{core} + M_\Lambda)$$

Binding energy of $^{12}\mathrm{C}(K^-,\pi^-)^{12}_{\Lambda}\mathrm{C}$



Total K^-: 0.18 x 10^9
$(CH)_n$ tgt. (9 g/cm^2)

$^{12}_{\Lambda}\mathrm{C}$ production events were observed.
→Feasibility of exp. by (K^-,π^-) at 0.9 GeV/c was confirmed.

Further analysis is ongoing.
→ Cross section at 0.9, 1.5, 1.8 GeV/c

Contents

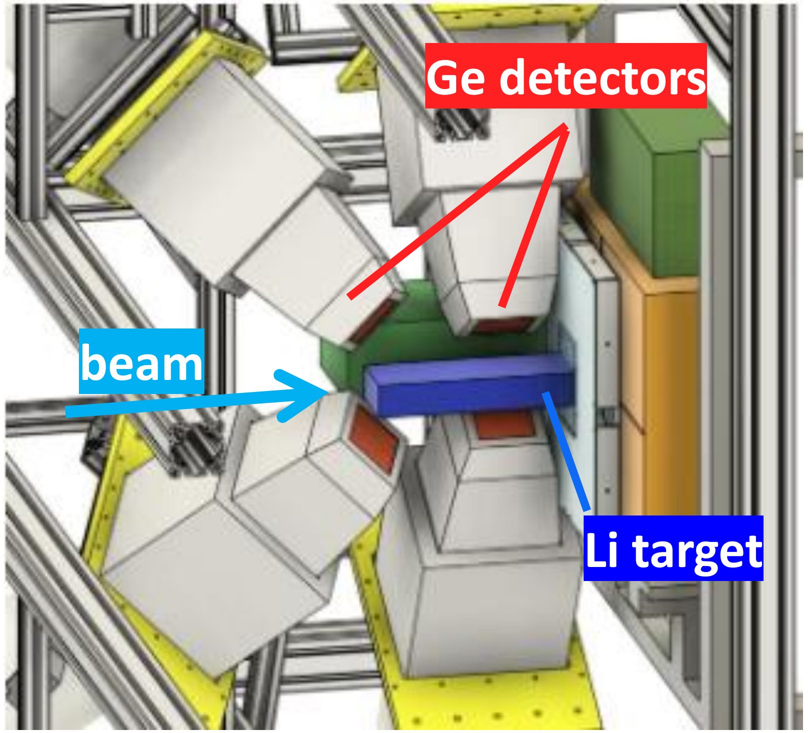
Experiment plan and schedule

- Physics beam time estimation
  - We can measure ${}^{4}_{\Lambda}\mathrm{H}$ γ-ray with 12-days beam time.
  - PAC approved our beam time request.

- Preparation and beam time plan
  - Beam line detectors are ready.
  - Ge detectors will be installed in Mid-Oct. 2025.

  - **We will start physics data-taking in Nov. 2025.**

Ge detector array (3D design)



Summary

- Measurements to date have revealed the existence of a large charge symmetry breaking (CSB) in ${}^{4}_{\Lambda}\mathrm{H}$ and ${}^{4}_{\Lambda}\mathrm{He}$.

- We plan a precise measurement of γ-ray from ${}^{4}_{\Lambda}\mathbf{H}(\mathbf{1}^{+} \rightarrow \mathbf{0}^{+})$ by a Ge detector array with the existing J-PARC K1.8 beam line + S-2S spectrometer.

- A beam test for the 0.9 GeV/c K^{-} beam have been performed.
  - Beam intensity check
  - (K^{-}, π^{-}) reaction check

- We are preparing for data-taking scheduled in Nov. 2025 (with 12 days beam time).