Search for Excited State of $^{4}_{\Sigma}$He Hypernucleus in the J-PARC E13 Experiment

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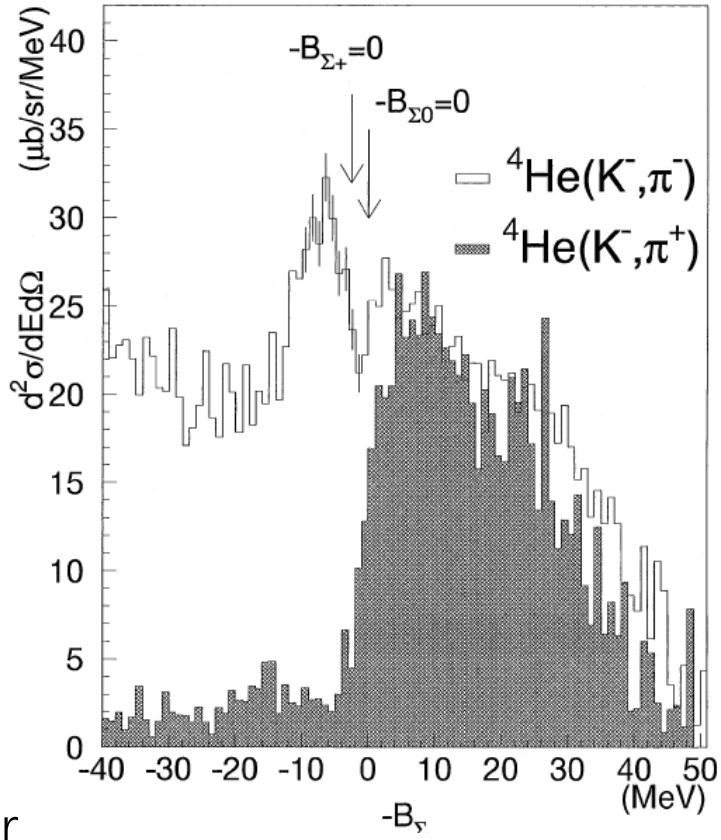
Contents

ΣN interaction Experiment

- Baryon-Baryon interaction
  - NN interaction is well studied
  - ΛN interaction is also studied.
- ΣN interaction
  - Σ^- atom → only sensitive to surface of nucleus
  - ΣN scattering → difficulty with short lifetime of Σ
    - Working at J-PARC (E40)
  - Σ hypernuclei
    - Possibility of systematic study with many species.
    - Currently only $^{4}_{\Sigma}$He is observed.

Σ hypernuclei search

- KEK-PS E167
  - First observation
  - But cusp couldn't be rejected
  - ^{4}He(stopped K^-, π^-)X reaction
- BNL-AGS E905
  - Confirm existence of $^4_\Sigma$He
  - ^{4}He(K^-, $\pi^\pm$)X reaction @0.6 GeV/c
- ^{4}He(K^-, π^-) reaction
  - Only ^{4}He(K^-, π^-) reaction can produce $^4_\Sigma$He
  - We study this in detail using higher momentum
    - Excited state of $^4_\Sigma$He, etc.



T.Nagae *et al.*, Phys.Rev.Lett. 80(1998)1605.

J-PARC E13 Experiment Collaboration

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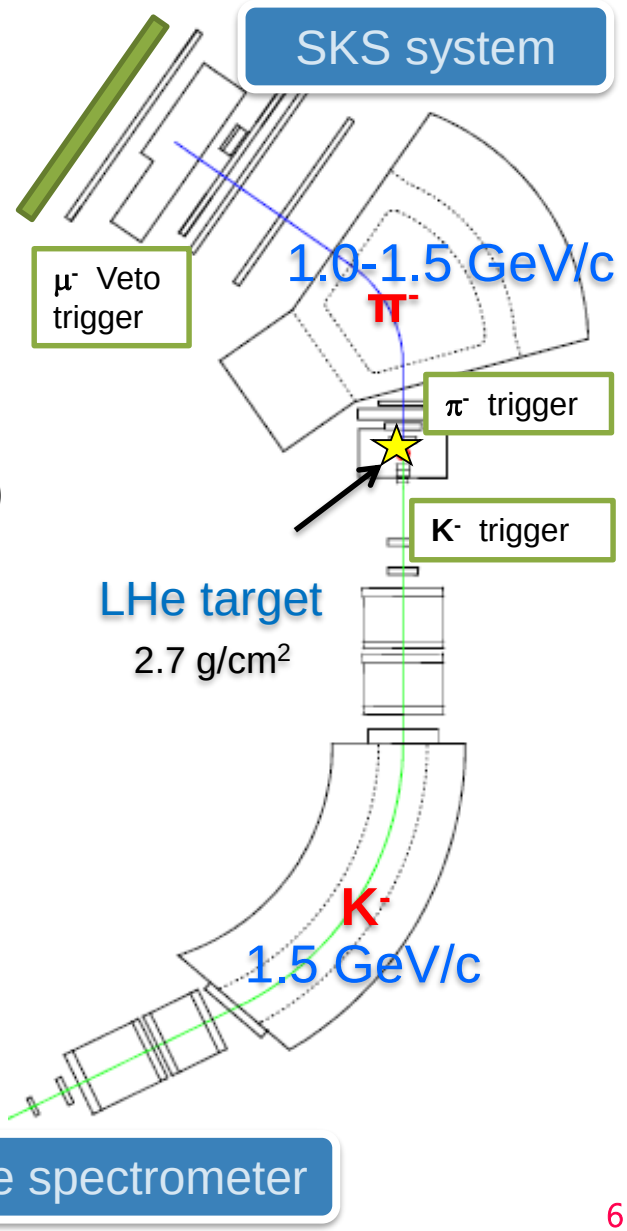
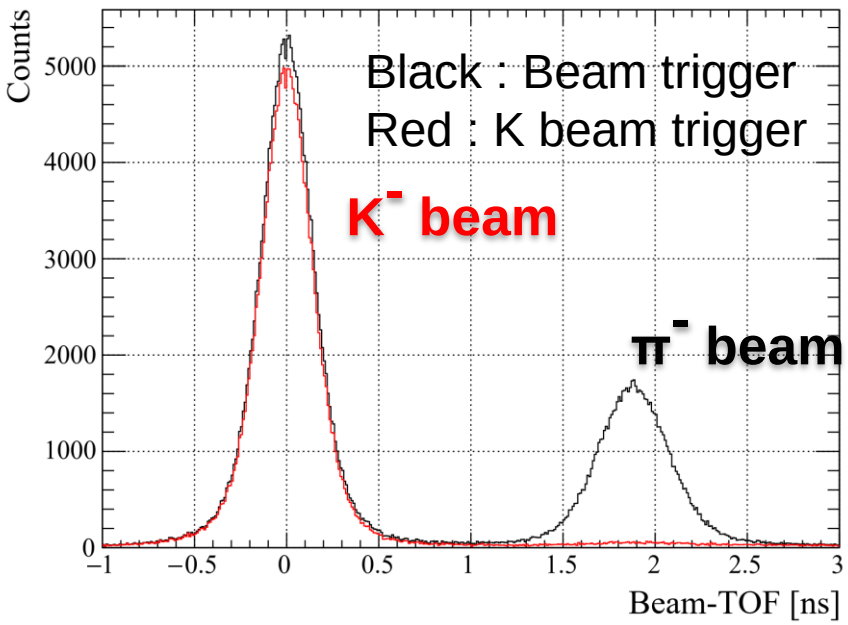
J-PARC E13 Experiment

- Physics
  - γ-ray spectroscopy of ${}^{4}_{\Lambda}$He
    - Charge symmetry breaking
      (T. O. Yamamoto, et al., PRL.**115**.222501)
  - Search for the excited state of ${}^{4}_{\Sigma}$He
    (this study)
- Method
  - Missing-mass spectroscopy
    of ^{4}He(K^-, π^-)X reaction
  - Scattering angle : 2-14 deg. (Lab sys.)
    - 4-28 deg. (CM sys.) $\cos\theta_{CM}$ = 0.9 - 1.0
  - Momentum : 1.0 – 1.5 GeV/c

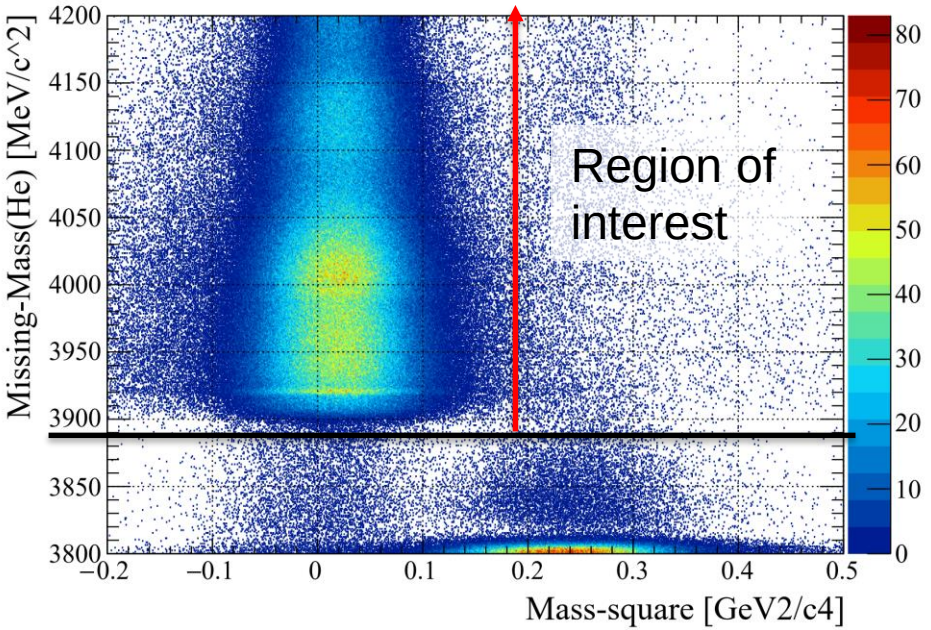


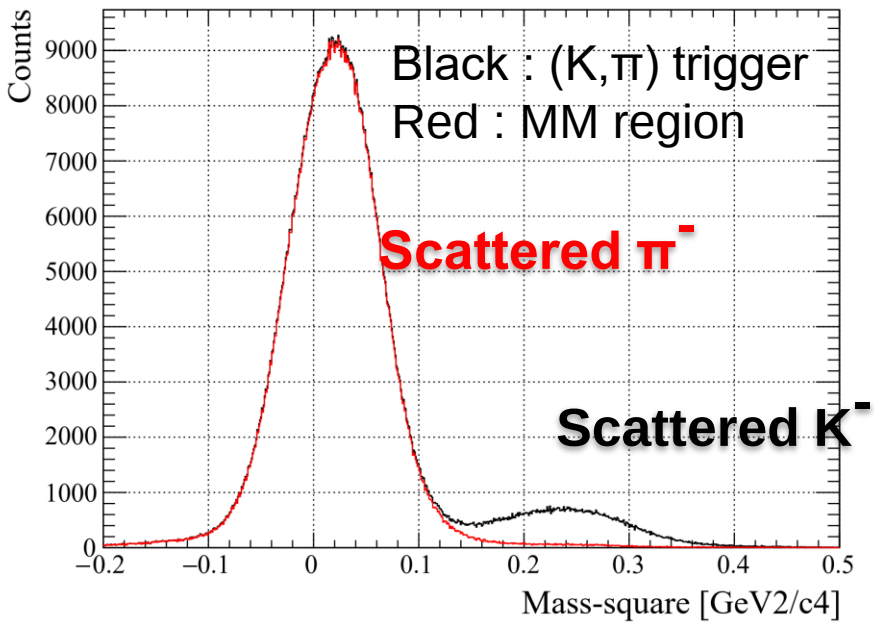
Analysis
Particle identification

- We can clearly identify K^- and π^-



Beam

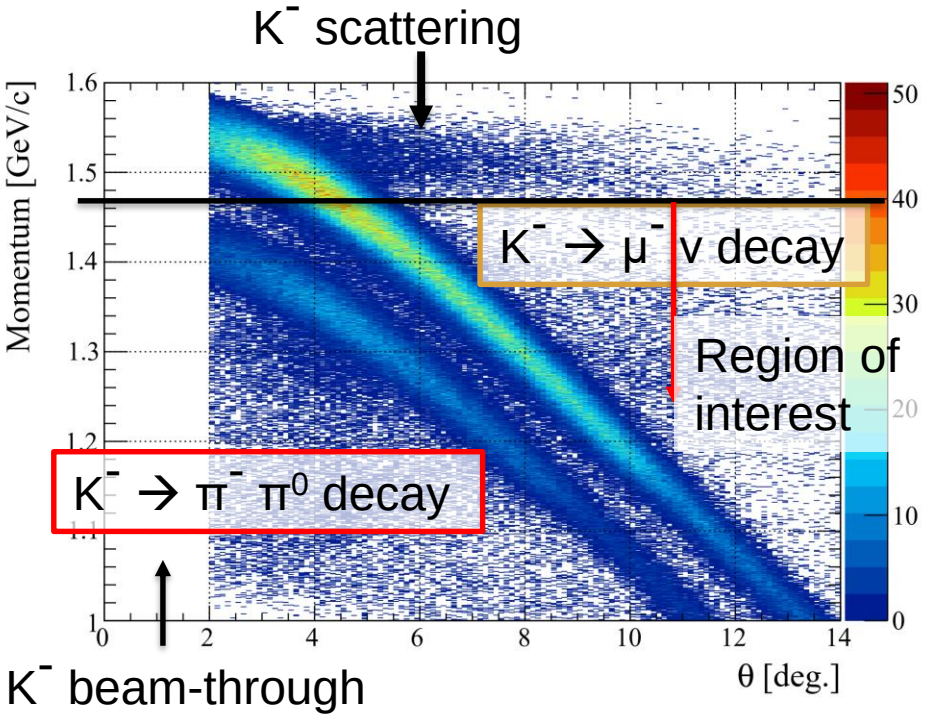




Scattered

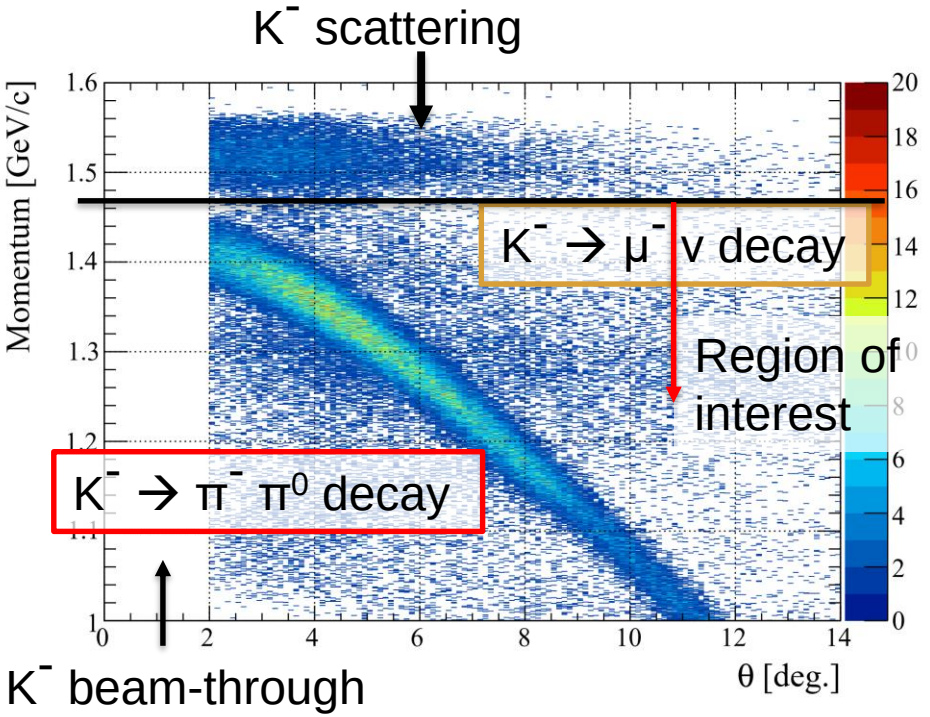
Analysis
Momentum reconstruction

- Momentum reconstruction
  - Beam : QQDQQ system
    - Momentum bite : 20 MeV/c
  - Scattered : Runge-Kutta method
- Background
  - Reject completely
    - K^- beam-through
    - K^- scattering
    - $K^- \rightarrow \mu^- \nu$ decay
      - Veto by Iron



Analysis
Momentum reconstruction

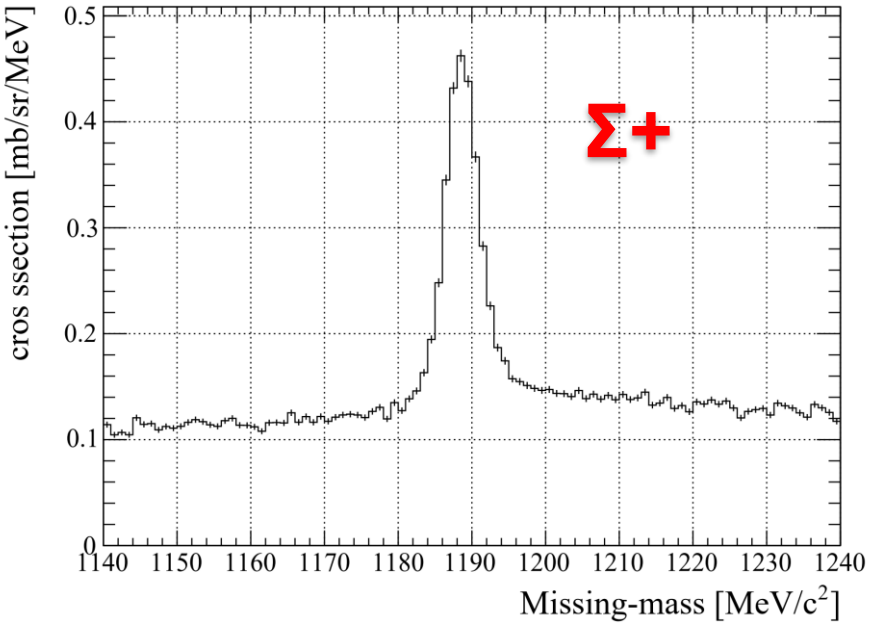
- Momentum reconstruction
  - Beam : QQDQQ
    - Momentum bite :
      20 MeV/c @ 1.5 GeV/c
  - Scattered :
    Runge-Kutta method
- Background
  - Reject efficiently
    - K^- beam-through
    - K^- scattering
    - $K^- \rightarrow \mu^- \nu$ decay
      - Veto by Iron
  - Difficult to reject
    - $K^- \rightarrow \pi^- \pi^0$ decay
      (Estimate by simulation)



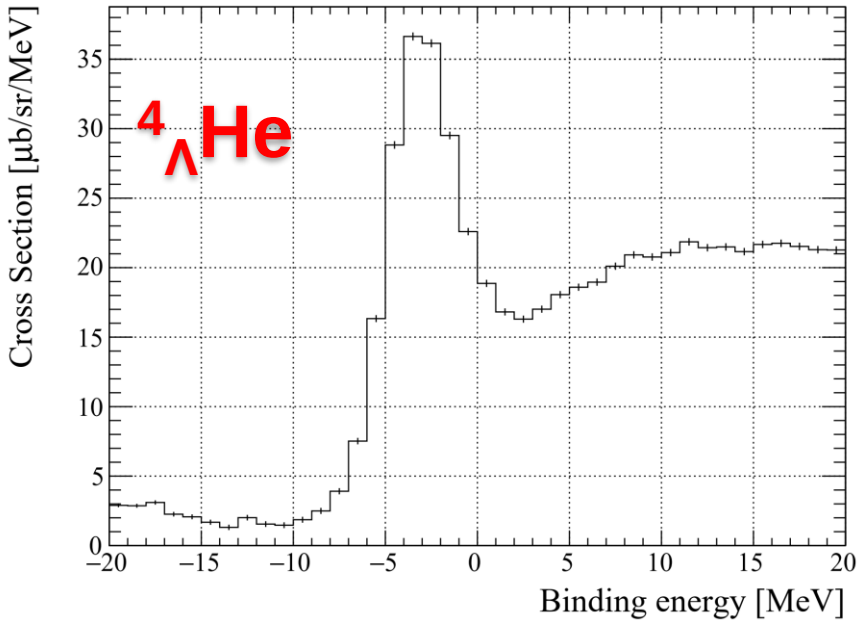
Analysis
Momentum calibration

- Use peaks of Σ^+ hyperon and $^4_\Lambda$He g.s.

Σ^+ : p(K^-, π^-)X reaction (CH2 target)



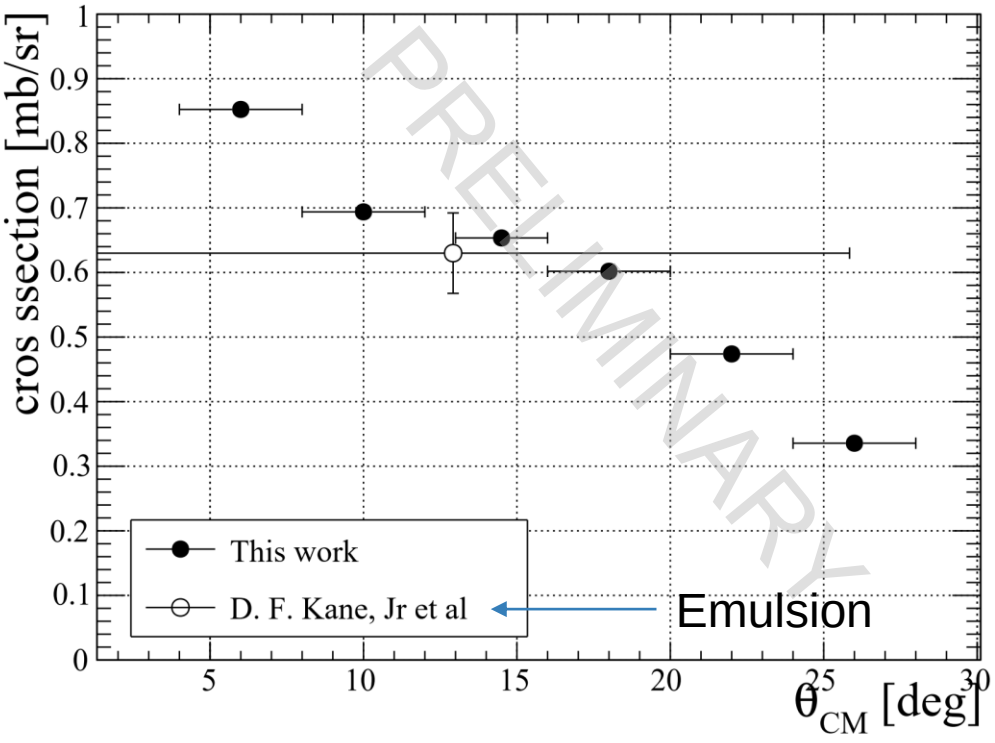
$^4_\Lambda$He : ^{4}He(K^-, π^-)X reaction



Resolution :
4.5 MeV FWHM

Results
Angular dependence of Σ^+ hyperon production

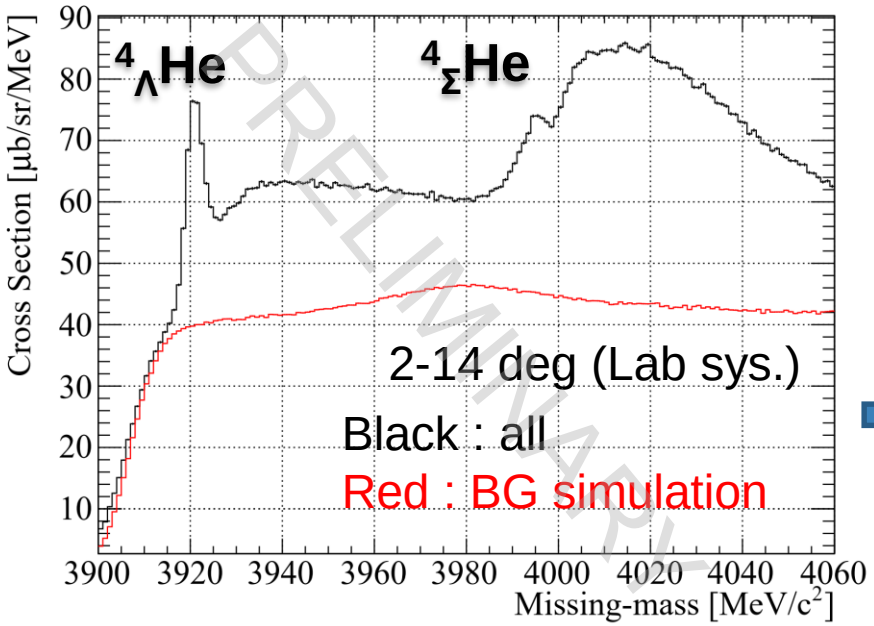
Cross section every 4 degrees (CM system)

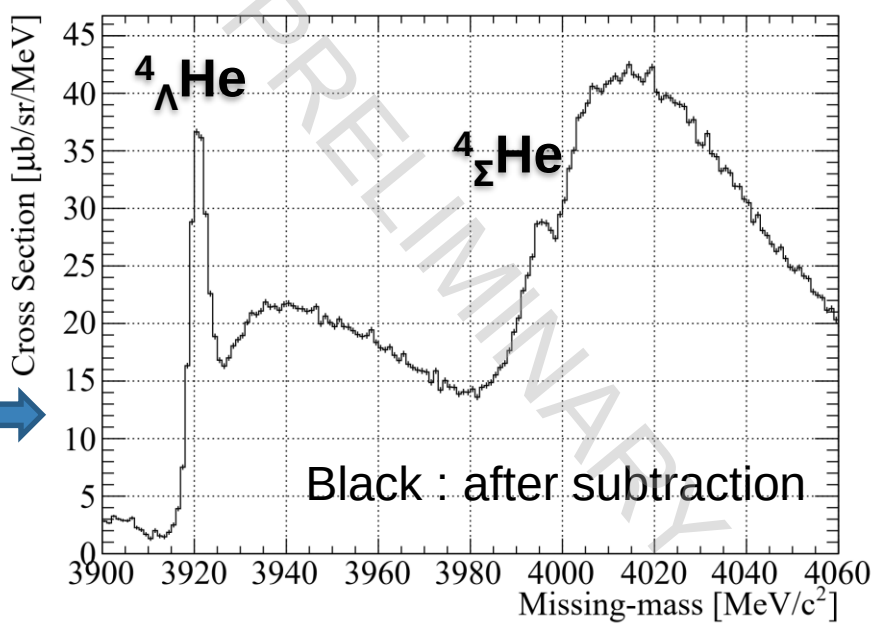


$\cos\theta_{CM} = 0.9 – 1.0$

- Detailed angular dependency measured.
- → Useful to adjust parameters of a theoretical calculation

Results
Missing-mass spectrum of ^{4}He(K^-, π^-)X reaction

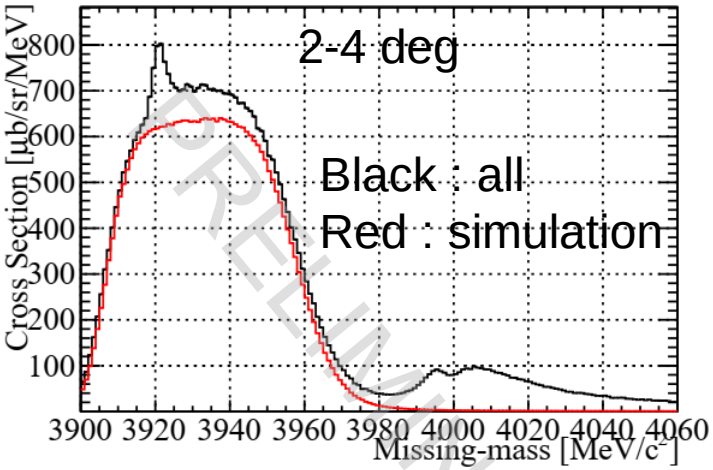


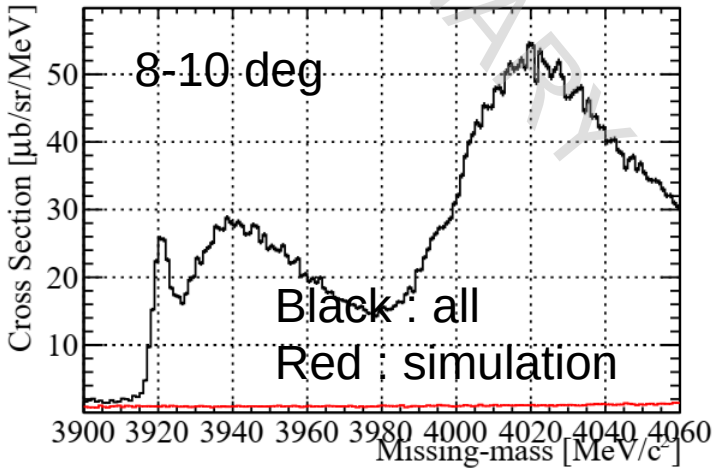


- Ground states of $^4_\Lambda$He and $^4_\Sigma$He are clearly observed
- Main background is $K^- \rightarrow \pi^- \pi^0$ decay
  - estimate and subtract the distribution

Results
Missing-mass spectrum of ^{4}He(K^-, π^-)X reaction

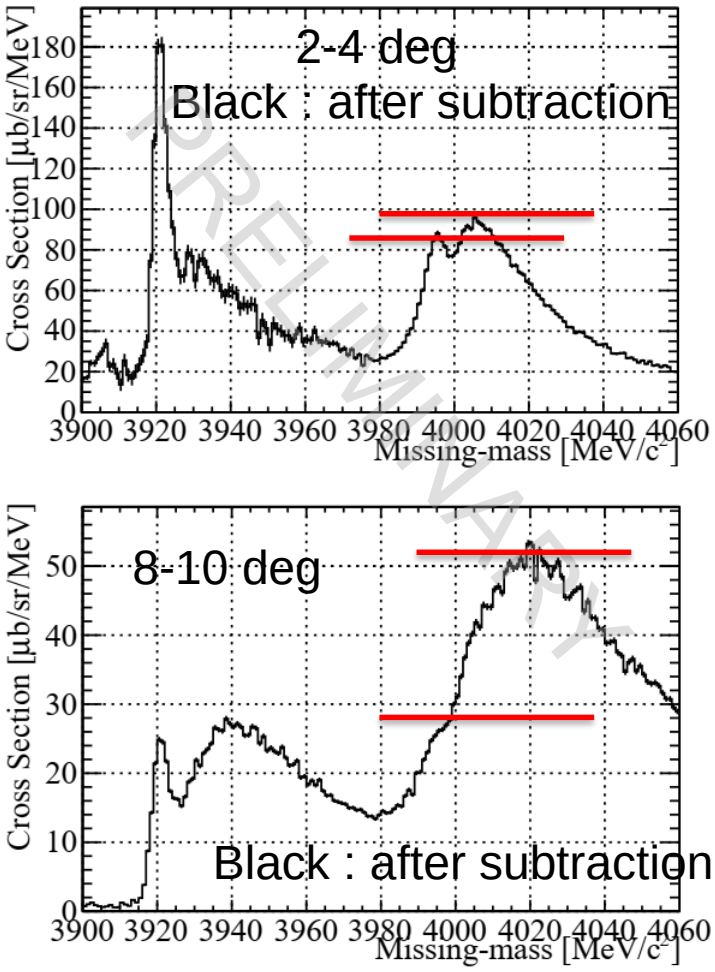
- Every 2 degrees (Lab sys.)
  - High statistics
- 2-4 deg.
  - BG is only under $^{4}_{\Lambda}$He
- 8-10 deg.
  - No BG





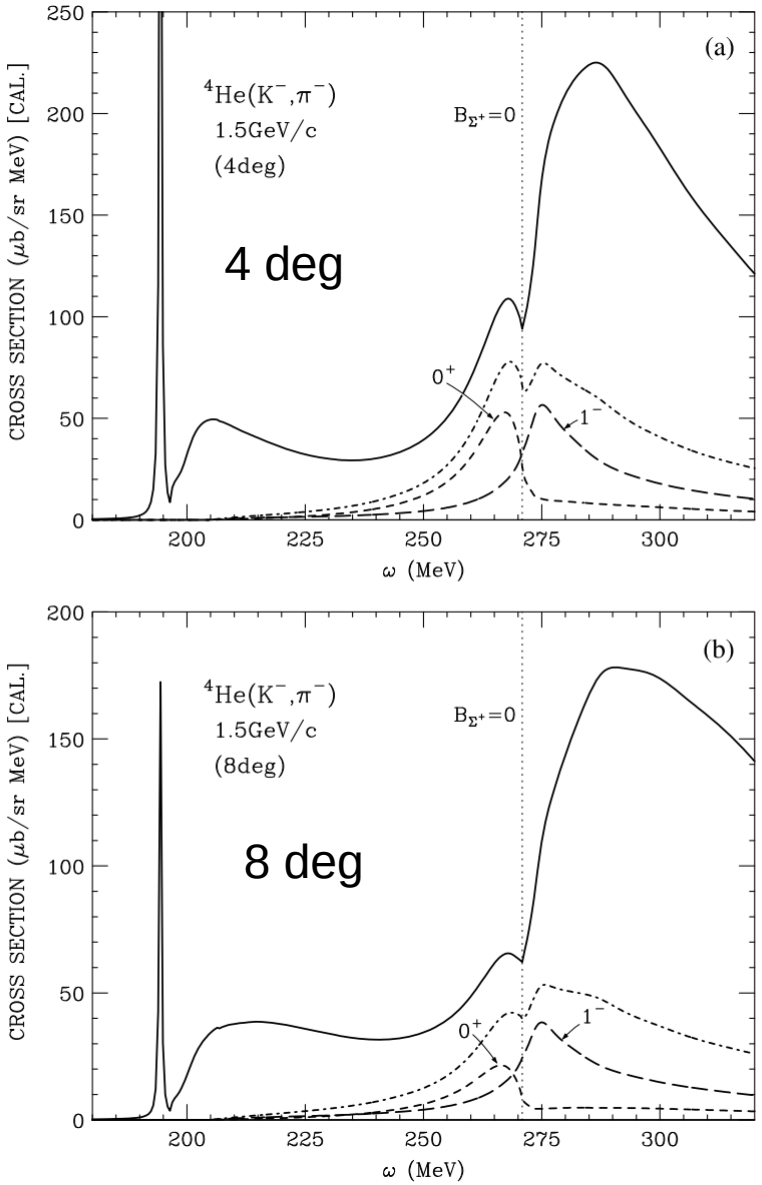
Results
Missing-mass spectrum of ^{4}He(K^-, π^-)X reaction

- Every 2 degrees (Lab sys.)
  - High statistics
- 2-4 deg.
  - BG is only under $^{4}_{\Lambda}$He
  - $^{4}_{\Sigma}$He g.s. : Σ QF = 1:1
- 8-10 deg.
  - No BG
  - $^{4}_{\Sigma}$He g.s. : Σ QF = 1:2



Discussion
theoretical calculation

- Condition
  - Parameters from various experimental data
- Any angle
  - $^{4}_{\Sigma}$He g.s. : Σ QF = 1:2



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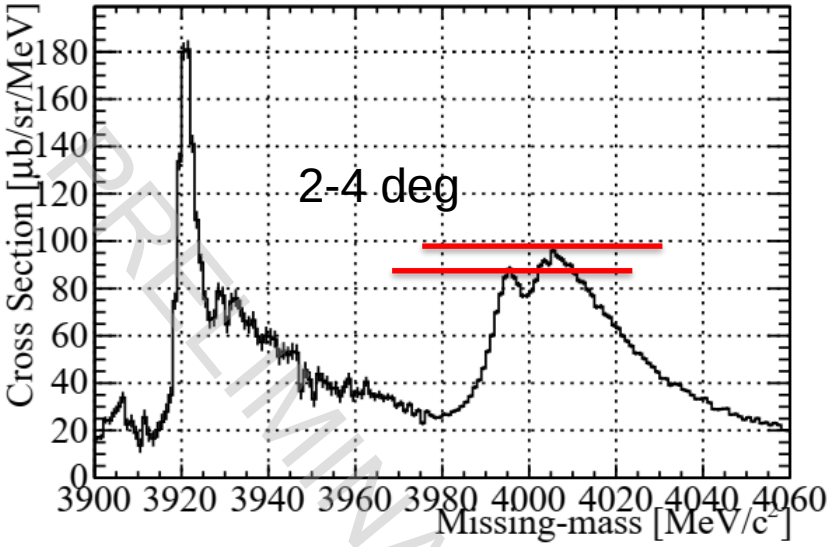

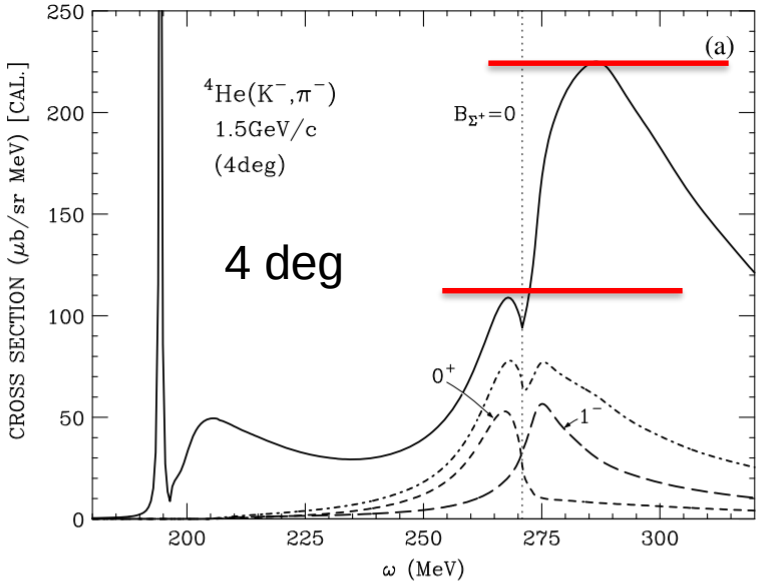

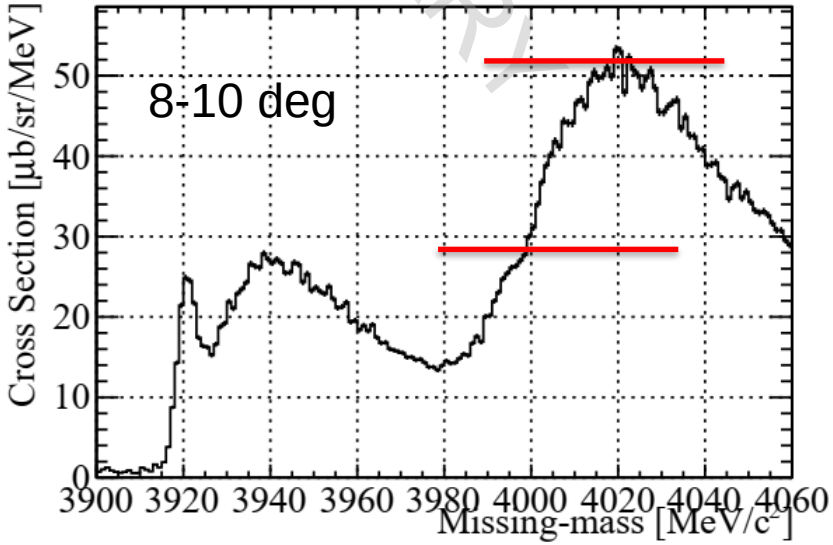

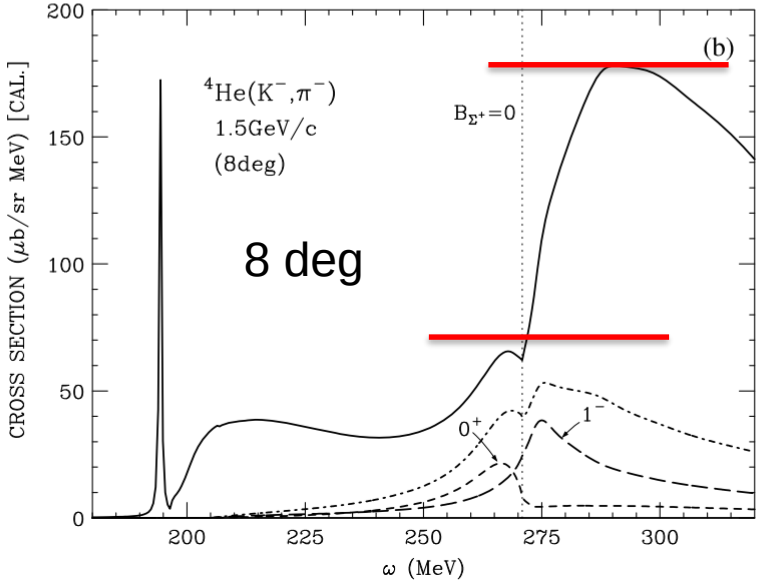

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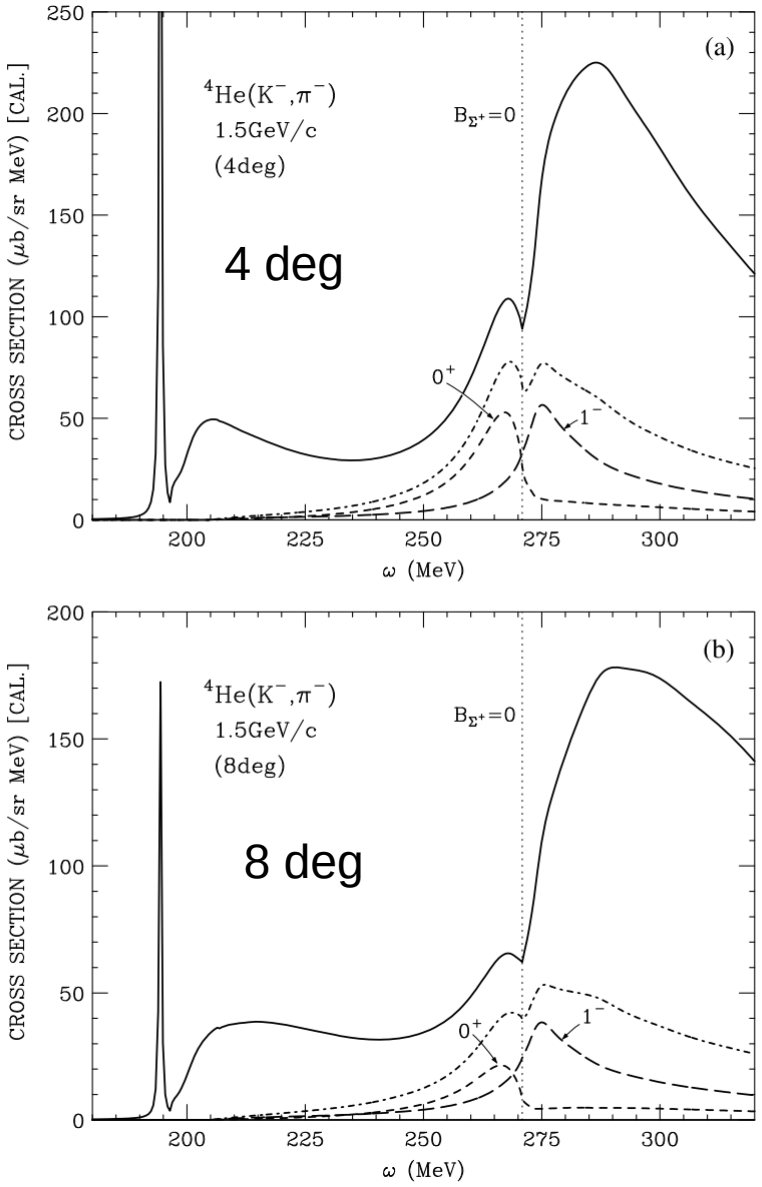
Discussion
theoretical calculation

- Why measured QF is small?
  - Interference effect doesn't change the ratio.
  - Possibility of energy dependence of elementary cross section
  - We can extract excited state after adjusting the parameters.



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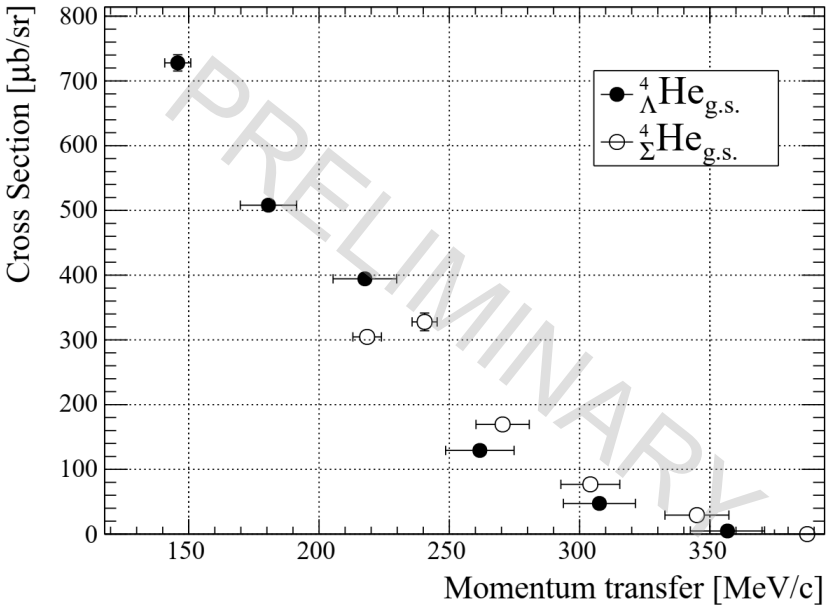
Results
Momentum transfer distributions of $^{4}_{\Lambda}$He and $^{4}_{\Sigma}$He

- Momentum transfer
  - Converted from angle
  - First high-statistics measurement.
- Form factor

Not same

  - Initial state : K^- ^{4}He
  - Final state : π^- $^{4}_{\Lambda}$He
  - Can be calculated with DWIA

→ Direct measurement of the size of Hypernuclei



Summary

- Study of ΣN interaction using $^{4}_{\Sigma}$He
- J-PARC E13 Experiment
  - Missing-mass spectroscopy of ^{4}He(K^-, π^-)X reaction
    - Use higher momentum
- Results
  - Angular dependence of Σ^+ production
  - Spectra of ^{4}He(K^-, π^-)X reaction
    - Observed Quasi-free (2-4 deg) is smaller than calculation.
  - Momentum transfer distributions of $^{4}_{\Lambda}$He g.s. and $^{4}_{\Sigma}$He g.s.
    - First measurement with high statistics.
      - Can measure the size of Hypernuclei directly.