Production of Neutron-Rich Lambda-Hypernuclei at J-PARC

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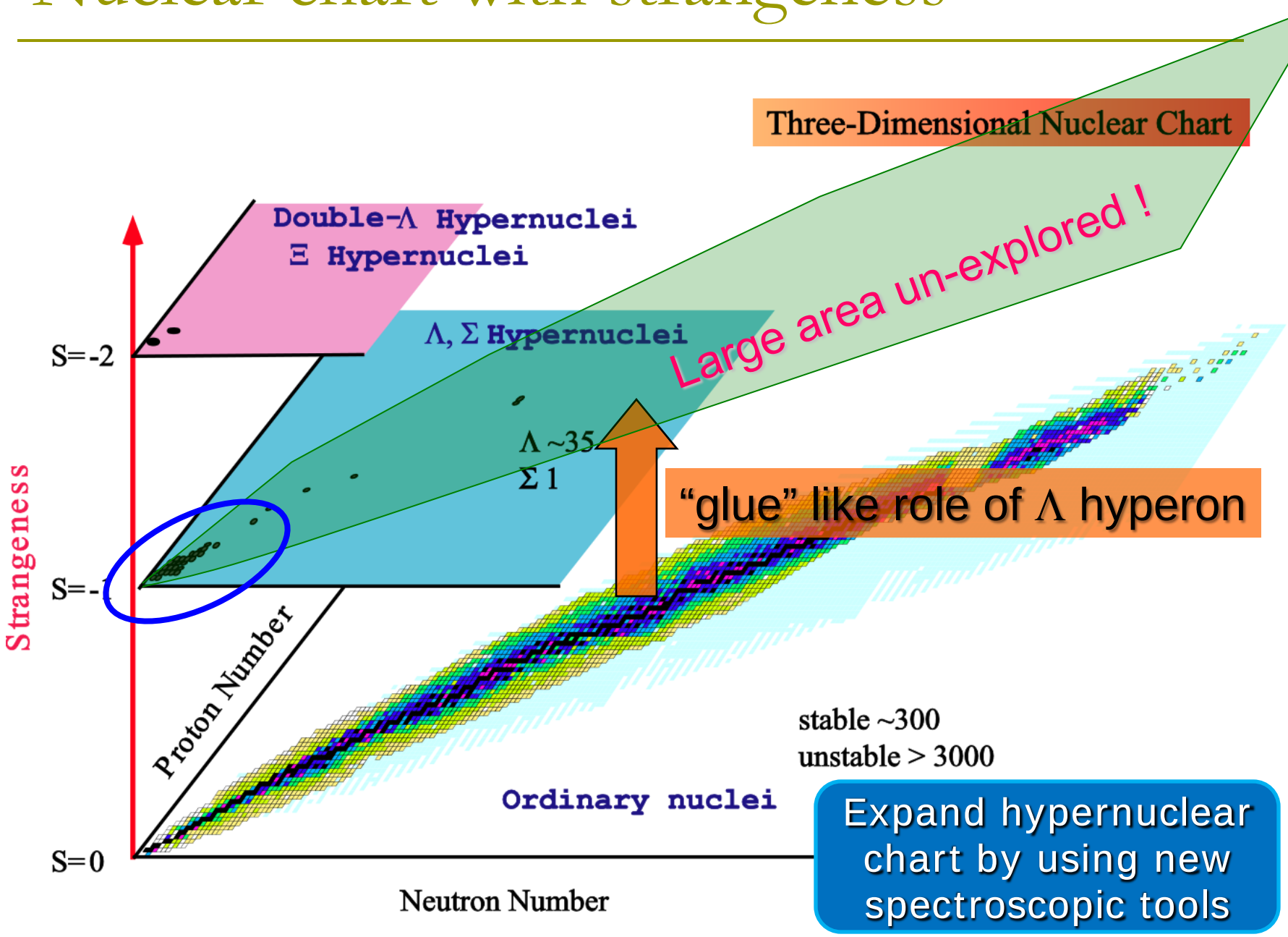
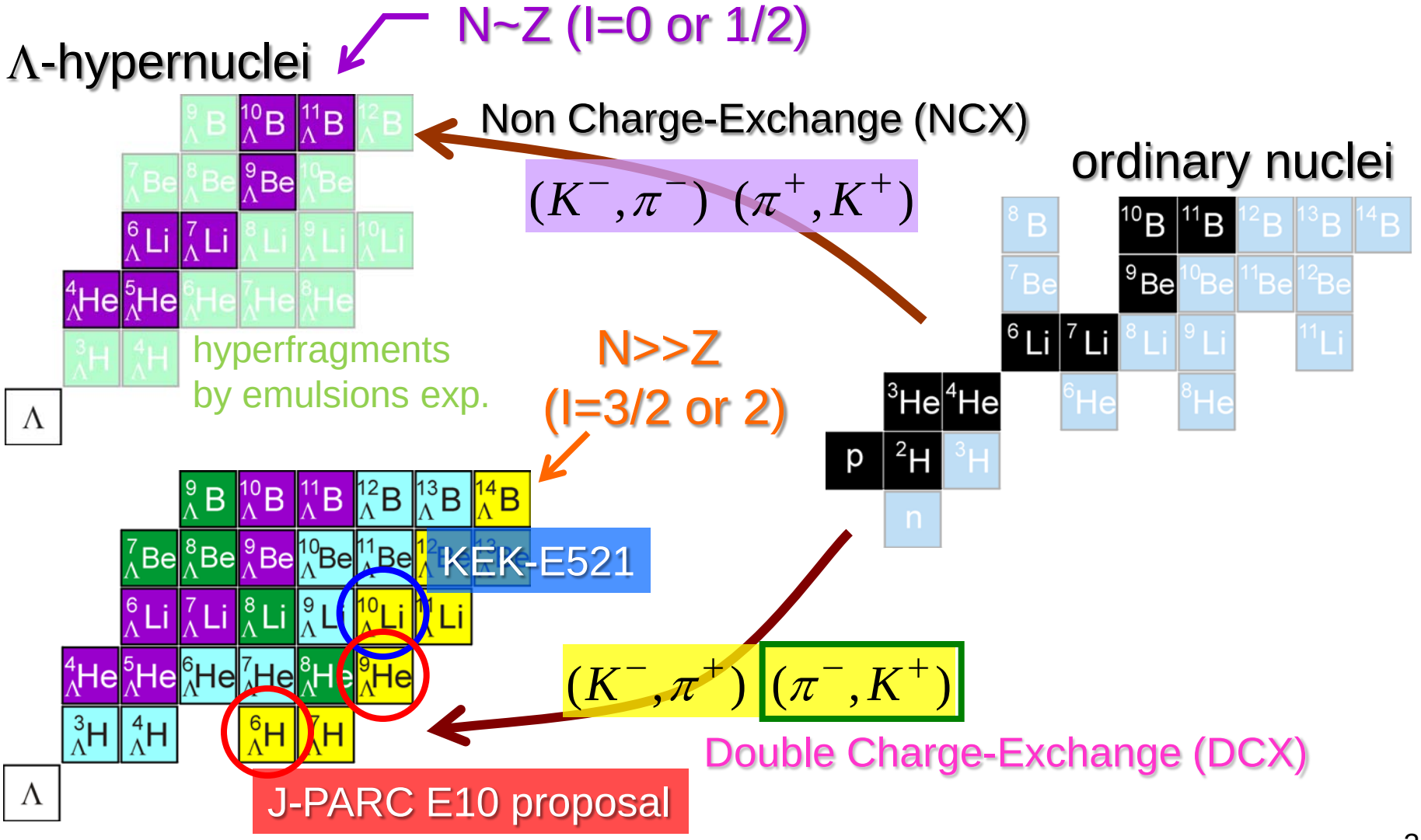
Nuclear chart with strangeness

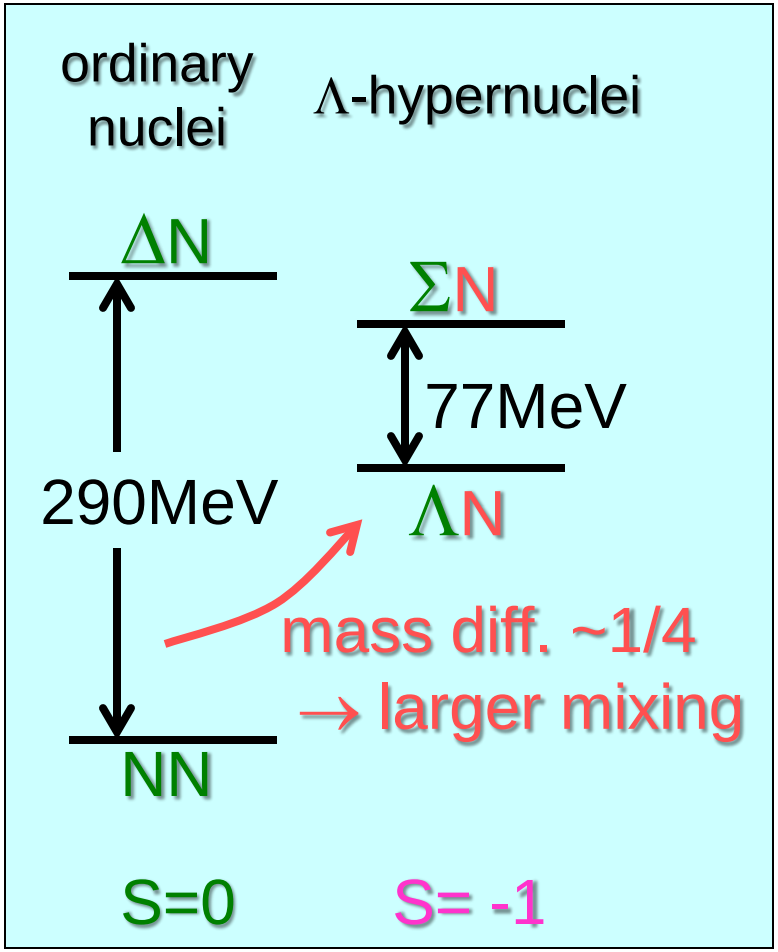


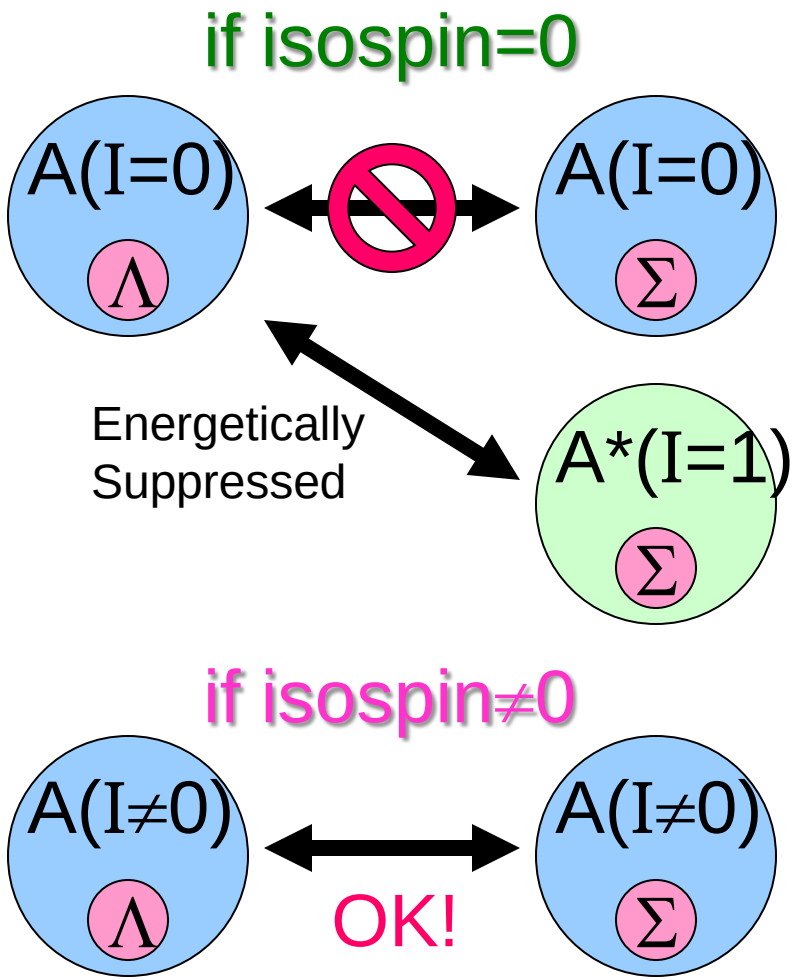
How we can expand hypernuclear chart

- Production of neutron-rich hypernuclei



ΛN-ΣN mixing





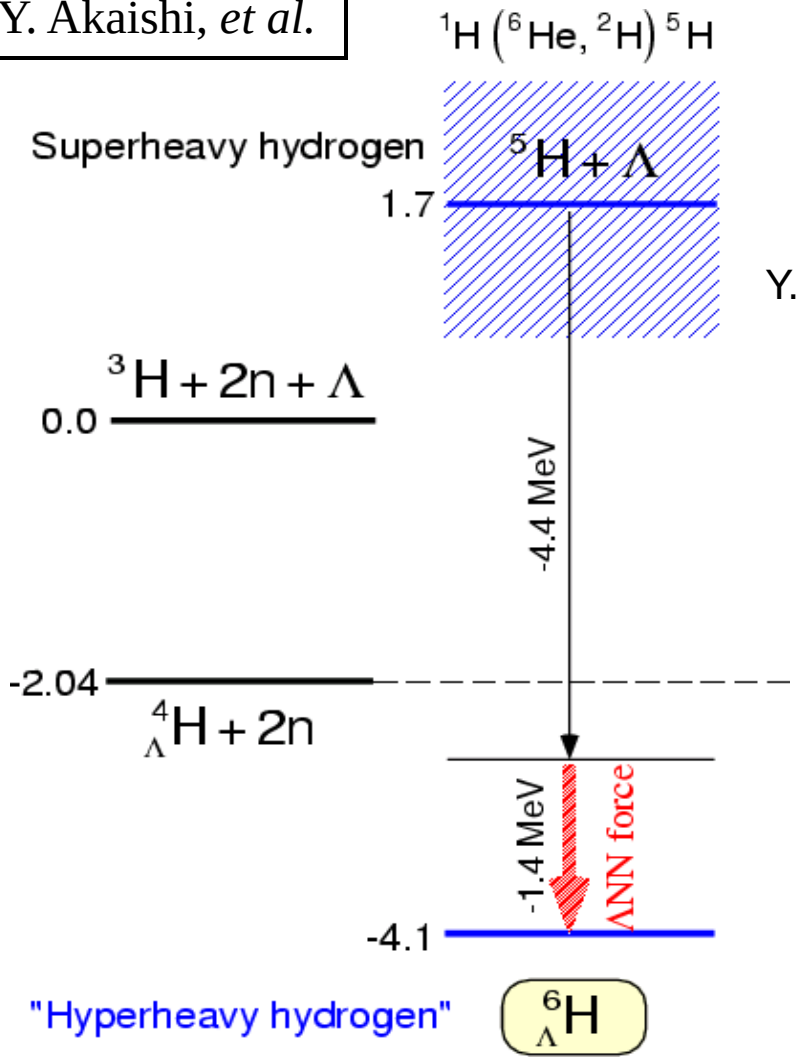
B.F. Gibson, A. Goldberg, M.S. Weiss (1972)

important in neutron-rich Λ-hypernuclei (large isospin)

Mixing effect in n-rich hypernuclei

- Binding energy info is important

Y. Akaishi, *et al.*



Coherent ΛN-ΣN mixing
originally introduced to explain A=3-5 hypernuclei

Y. Akaishi, T. Harada, S. Shinmura, K.S. Myint (2000)

Normal ΛN interaction

$B_Λ$ ~ 4.4 MeV

ΛN-ΣN mixing effect

$B_Λ$ ~ 4.4 + 1.4 MeV

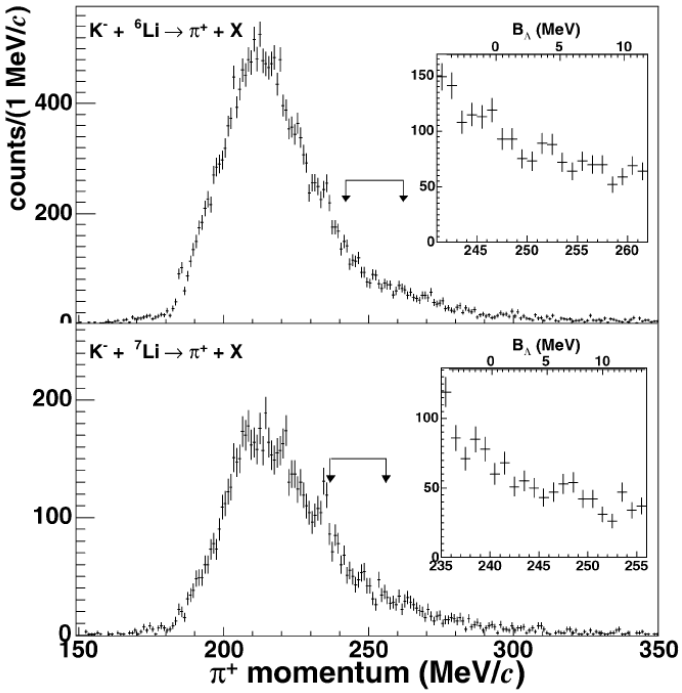
Precise measurement of B.E.

→ Estimation of mixing effect

Experimental studies

- Stopped K^- beam experiments
  - Measurement of (stopped K^-,π^+) reaction
  - KEK-PS
    - K. Kubota, et al. (1996)
      - ${}^{9}_{\Lambda}\mathrm{He}$/stopped-$K^-$ < 2.3×10^{-4}
      - ${}^{12}_{\Lambda}\mathrm{Be}$/stopped-$K^-$ < 6.1×10^{-5}
      - ${}^{16}_{\Lambda}\mathrm{O}$/stopped-$K^-$ < 6.2×10^{-5}
  - DAΦNE-FINUDA
    - M. Agnello, et al. (2005,2006)
      - ${}^{6}_{\Lambda}\mathrm{H}$/stopped-$K^-$ < 2.5×10^{-5}
      - ${}^{7}_{\Lambda}\mathrm{H}$/stopped-$K^-$ < 4.5×10^{-5}
      - ${}^{12}_{\Lambda}\mathrm{Be}$/stopped-$K^-$ < 2.1×10^{-5}
  - Expectation by simple estimation ~ 10^{-7}
  - Strong background from hyperon decay

FINUDA data



Production by (π^-,K^+) reaction

- KEK-E521 experiment established
  - $^{10}B\left(\pi^-,K^+\right)^{10}_{\Lambda}Li$ reaction

Clean reaction

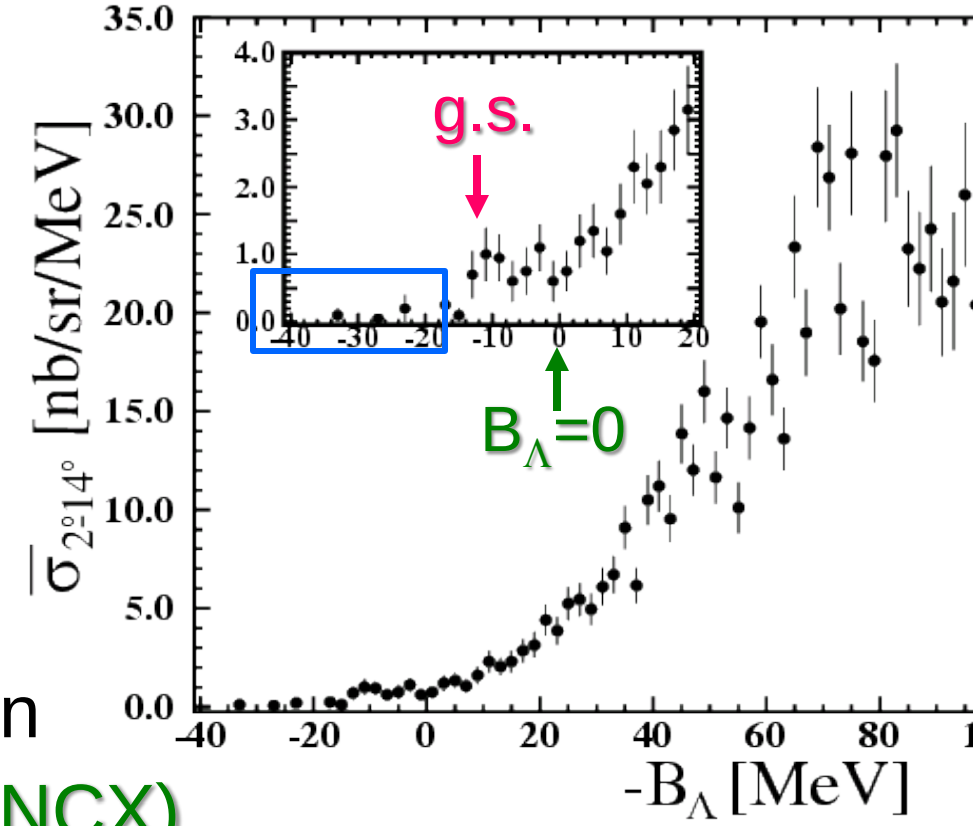
almost no background

Good energy resolution

K6 beam line @KEK-PS

SKS spectrometer

ΔB_Λ = 2.5MeV (FWHM)



~45 events in bound region

dσ/dΩ~10nb/sr (1/1000 of NCX)

Increase yield ×10 at J-PARC

Reaction mechanism and Λ-Σ mixing

- Puzzling cross section

E521 result		
p_{beam}	1.05 GeV/c	1.2 GeV/c
$\sigma_{exp.}$	5.8 nb/sr	11.3 nb/sr

  - Naïve two-step reaction

$$\pi^- + p \to K^0 + \Lambda, \quad K^0 + p \to K^+ + n$$
$$\pi^- + p \to \pi^0 + n, \quad \pi^0 + p \to K^+ + \Lambda$$

$$\sigma(1.05\,\text{GeV/c}) > \sigma(1.2\,\text{GeV/c})$$

- Possible explanation by one step process
  - One-step reaction with ΛN-ΣN mixing

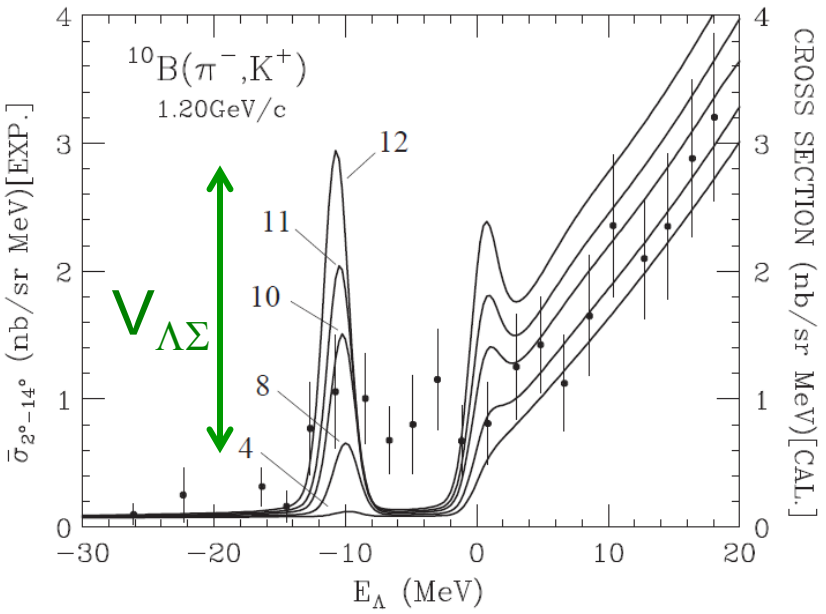
$$\pi^- + p \to K^+ + \Sigma^-, \quad (\Sigma^- p) \to (\Lambda n)$$

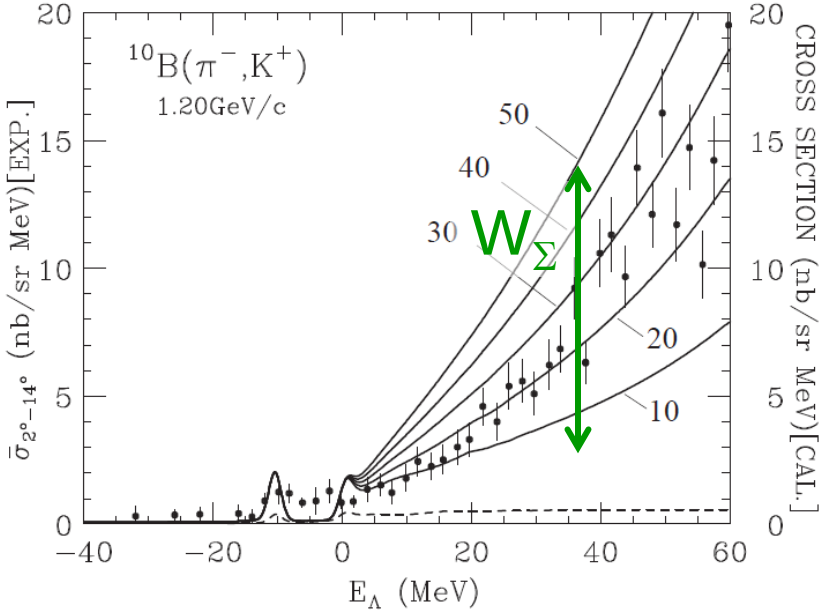
Σ channel opens at 1.045GeV/c

$$\sigma(1.05\,\text{GeV/c}) < \sigma(1.2\,\text{GeV/c})$$

  - Several theoretical calculations
    - T.Yu. Tretyakova and D.E. Lanskoy (2003)
    - T. Harada, A. Umeya and Y. Hirabayashi (2008)

- Λ-Σ coupled channel calc. of $^{10}B(\pi^-,K^+)$ reaction by Harada, Umeya and Hirabayashi
  - Spectrum is sensitive $V_{\Lambda\Sigma}$ and W_Σ





- Measurement of bound and continuum regions
  - Λ-Σ mixing phenomenon ($V_{\Lambda\Sigma}$)
  - Σ-nucleus interaction (W_Σ)

K1.8 beam line and SKS

High intensity K beams (<1.8GeV/c)

High intensity π beams

π beam intensity ~15M π-/spill

SKS spectrometer

move KEK → J-PARC

Excellent resolution

Large acceptance

Yield estimation for $^{9}_{\Lambda}$He production

- Cross section ~10nb/sr (~1/1000 of NCX)
- Major difficulty in this experiment

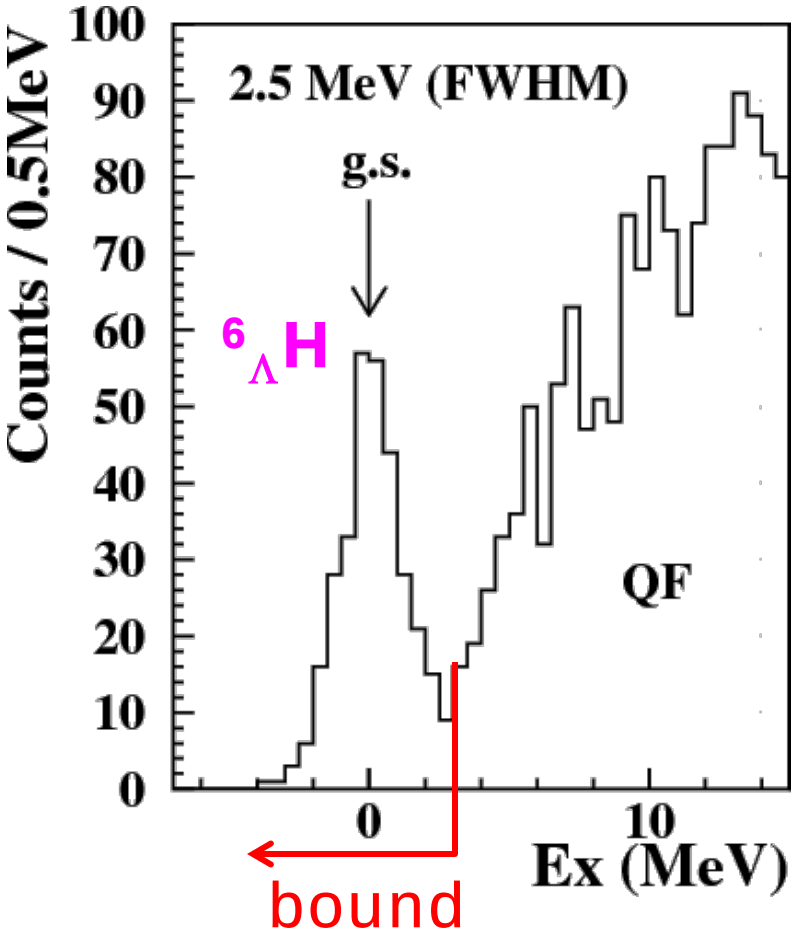
Parameters	Values	
π^- beam momentum	1.2 GeV/c	
π^- beam intensity	**1.5 x 10^7 /spill**	← High intensity beams
PS acceleration cycle	5.7 s/spill	
^{9}Be target thickness	3.5 g/cm^2	
Reaction cross section	10 nb/sr	
Spectrometer solid angle	**0.1 sr**	← Large acceptance
Spectrometer efficiency	0.5	
Analysis efficiency	0.5	

- About 300 events in 3 weeks of beamtime
  - 7 times larger ← KEK-E521 (47 events)
  - Discussion on level structure possible with new data

Prospects on B.E. measurement

- Measurement of B.E. of ${}^{6}_{\Lambda}$H

simulated spectrum



Assumptions

energy resolution	≈ 2.5 MeV(FWHM)
${}^{6}_{\Lambda}$H yield	≈ 300 events
${}^{6}_{\Lambda}$H/QF ratio (Ex<23MeV)	≈ 1/10

Good separation of bound and QF

Statistical error of B.E. < 0.1MeV

Minimize systematic errors

Wider momentum coverage of SKS

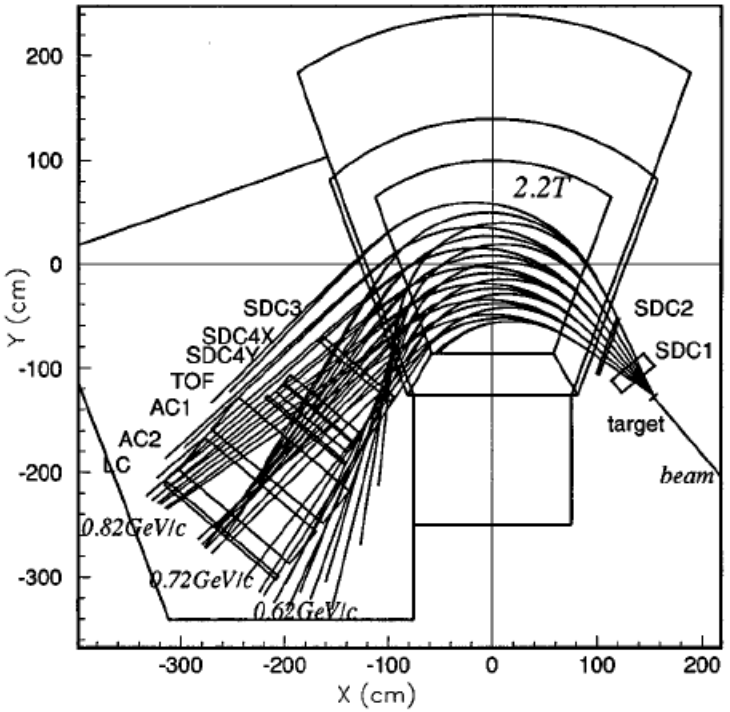
Λ-bound, Λ-QF and Σ regions

understand reaction mechanism

monitoring of system stability

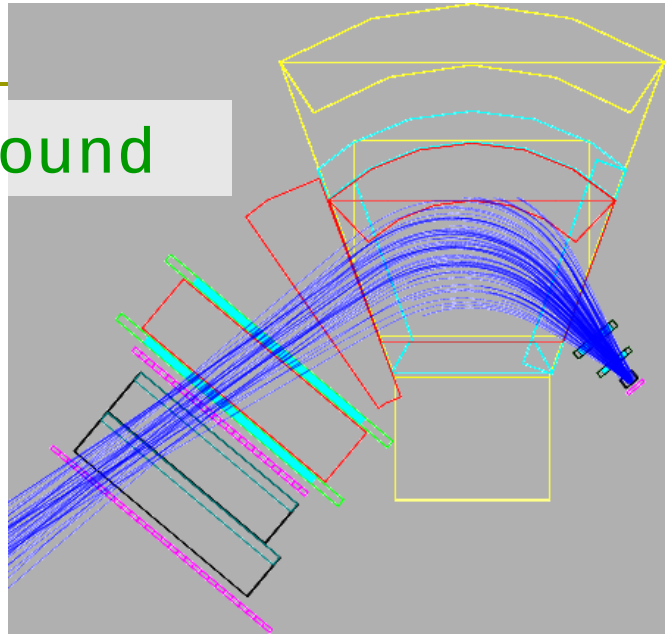
SKS spectrometer

- Detector upgrade
  - Wider momentum acceptance

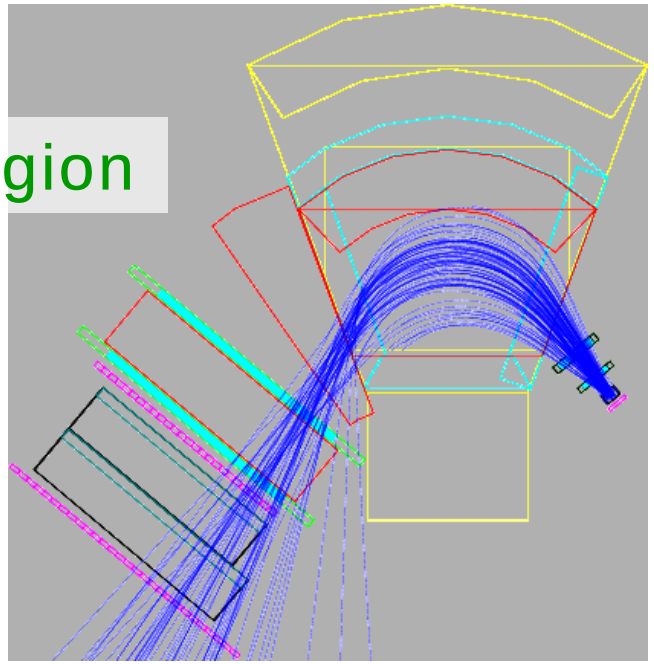


Optimized for Λ-bound region

Λ-bound



Σ-region



Summary

- We need new spectroscopic tools to expand the hypernuclear chart
  - Further study on the S=-1 system
  - DCX reaction is a candidate and promising

- J-PARC E10 proposal
  - Produce neutron-rich Λ-hypernuclei by DCX
  - Use K1.8 beam line and SKS spectrometer
  - Study exotic hypernuclei ($^{6}_{\Lambda}$H, $^{9}_{\Lambda}$He)
  - Increase yield (×~10) from E521
  - Investigate ΛN-ΣN mixing effect
    - Measurement of binding energies of n-rich HY
    - Measurement of wide range of (π^-,K^+) spectra