E10 experiment on neutron-rich hypernuclei

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for the **J-PARC E10** Collaboration

(talk is based on Phys. Lett. B729 (2014) 39)

J-PARC E10 collaboration

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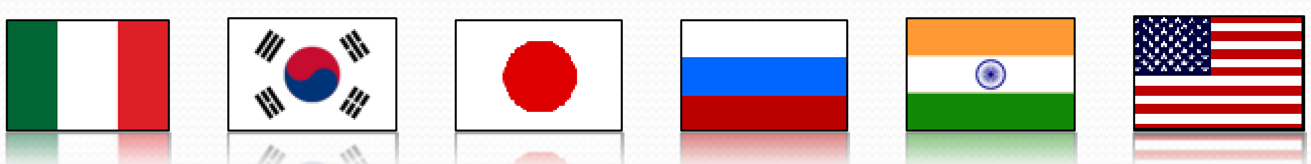
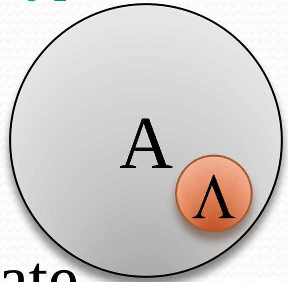
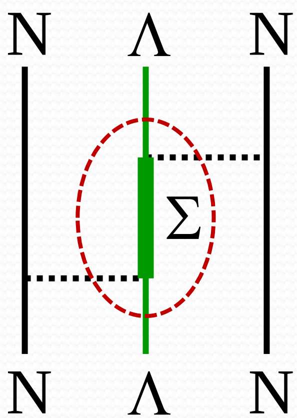


Λ hypernuclei and ΛN interaction

hypernucleus



- Λ hypernucleus and hypernuclear studies
  - System made of a Λ hyperon and a nucleus(A)
  - ΛN interaction strong enough to form a bound state
  - Properties of ΛN interaction were extensively studied by measurements of hypernuclear structures
- How far can we extend the hypernuclear chart?
  - Importance of "glue-like role" of Λ hyperon
  - ΛN interaction also stabilize host nucleus
- How about the ΛNN 3-body force?
  - Prediction of a strong ΛNN 3-body force
  - Force comes from ΛN-ΣN mixing process

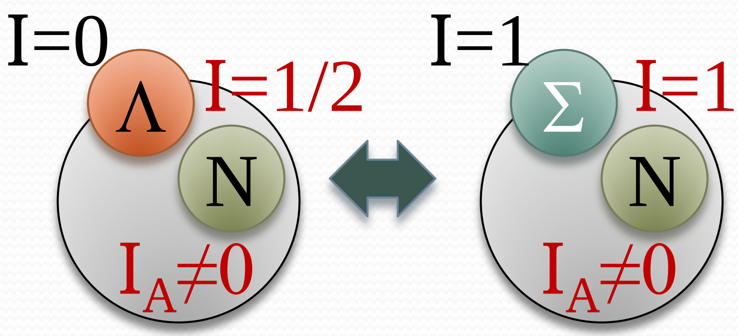


Aims of J-PARC E10 experiment

- **Aim 1**: Λ hypernuclei close to the neutron drip-line
  - E10 may produce highly neutron-rich Λ hypernuclei
    - $^{6}_{\Lambda}H$ (1p, 4n and 1Λ), $^{9}_{\Lambda}He$ (2p, 6n and 1Λ)
    - Exotic hypernuclei we have never seen clearly
  - "glue-like role" of Λ hyperon is critical in such loosely bound hypernuclei
- **Aim 2**: ΛN interaction at the extreme condition
  - Effect of ΛN-ΣN mixing or ΛNN 3-body force may be observed in structures of neutron-rich hypernuclei
  - Neutron-rich Λ hypernuclei are good laboratories to study these effects

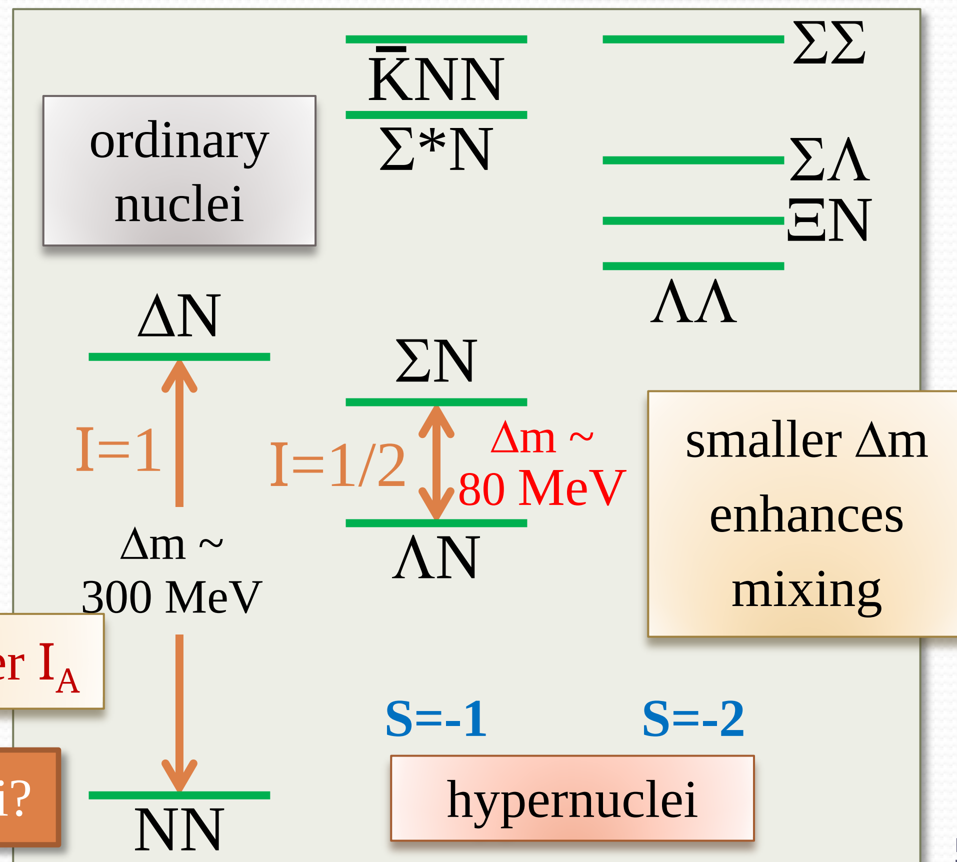
ΛN-ΣN Mixing and n-rich Λ Hypernuclei

- Strong mixing of ΛN and ΣN pairs
  - B.F. Gibson et al. PR C6 (1972) 741



overall conservation of isospin is required
nucleus is buffer of isospin

BB spectrum

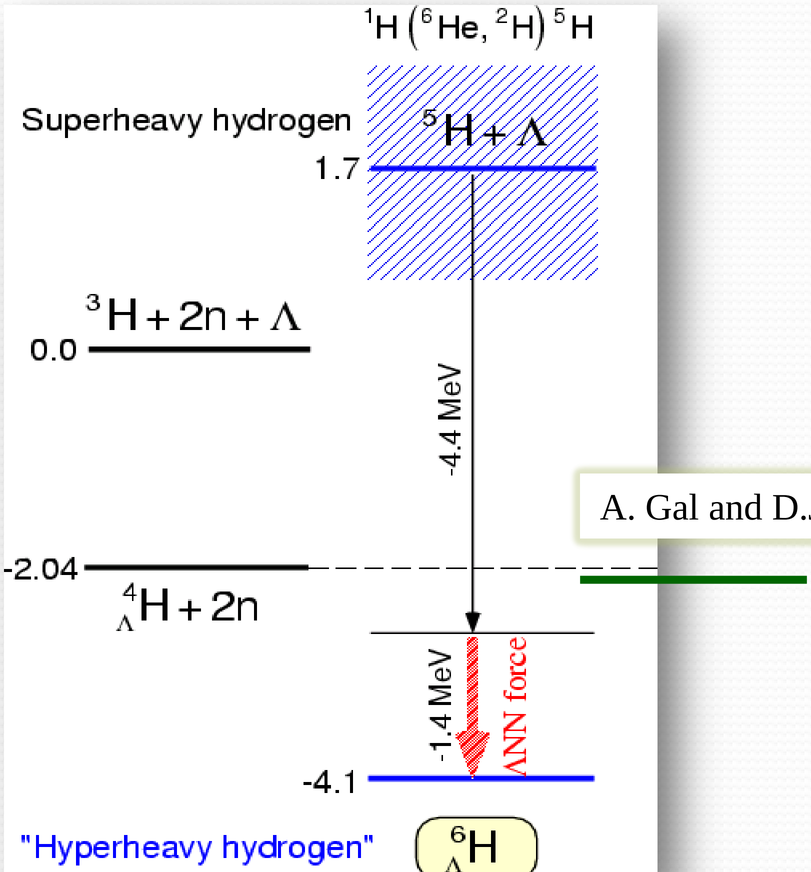


larger mixing in host nucleus with larger I_A

How large mixing in n-rich hypernuclei?

Mixing and n-rich hypernucleus $^{6}_{\Lambda}$H

- Possible observation of mixing effect in $^{6}_{\Lambda}$H structure



A. Gal and D.J. Millener, Phys. Lett. B 725 (2013) 445

Y. Akaishi and T. Yamazaki, Frascati Phys. Ser. XVI (1999) 59

Prediction of Akaishi and Yamazaki

Normal ΛN interaction ("glue" effect)
B_{Λ} ~ 4.4 MeV

Coherent ΛN-ΣN mixing
B_{Λ} ~ 4.4 + 1.4 MeV

Prediction of Gal and Millener

Coherent ΛN-ΣN mixing
$\Delta B_{\Lambda N\text{-}\Sigma N}$ ~ 0.1 MeV

Structure of $^{6}_{\Lambda}$H should be investigated experimentally

Structure of $^{6}_{\Lambda}$H hypernucleus

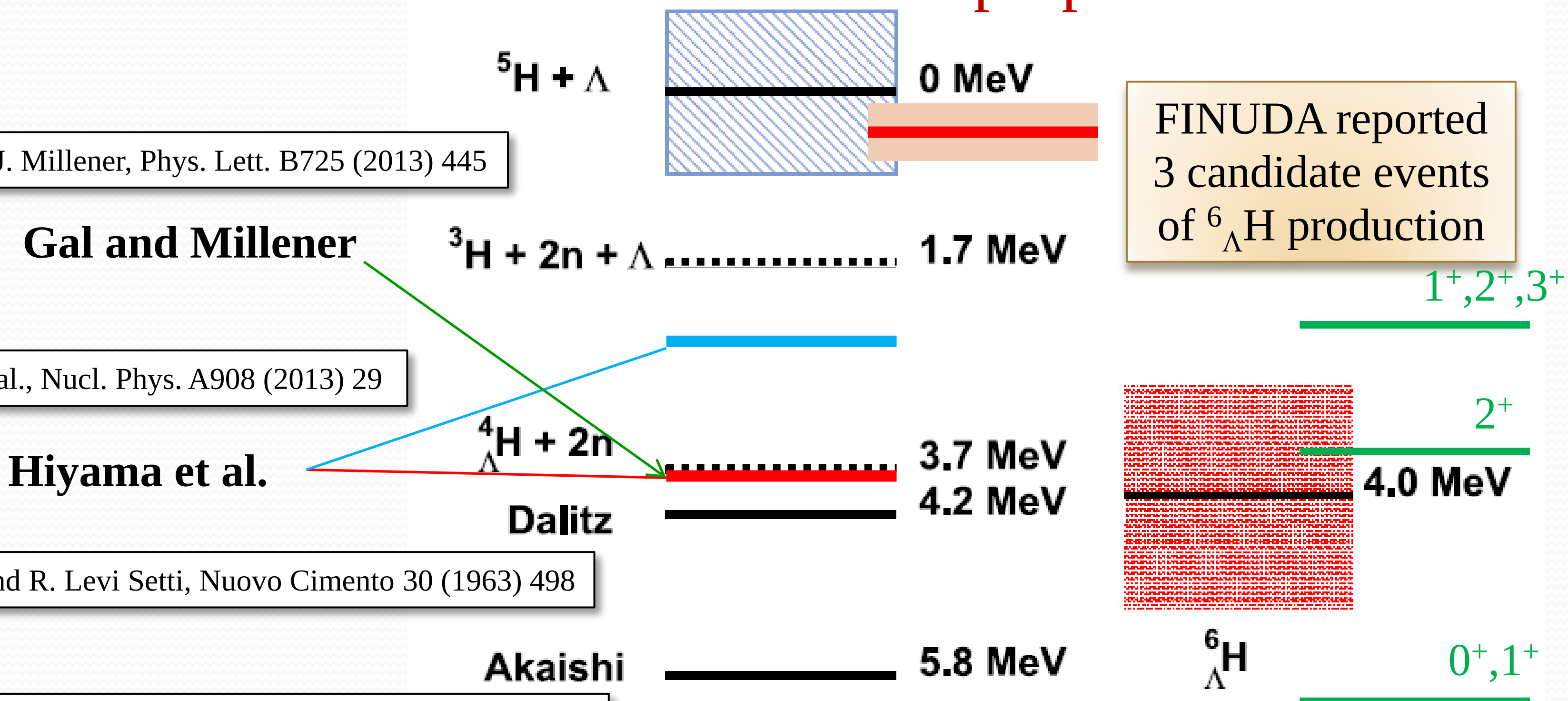
- FINUDA reported 3 candidate events of $^{6}_{\Lambda}$H production
- Sensitive to ΛN interaction and also properties of ^{5}H

A. Gal and D.J. Millener, Phys. Lett. B725 (2013) 445

E. Hiyama et al., Nucl. Phys. A908 (2013) 29

R. H. Dalitz and R. Levi Setti, Nuovo Cimento 30 (1963) 498

Y. Akaishi and T. Yamazaki, Frascati Phys. Ser. XVI (1999) 59



M. Agnello et al., FINUDA Collaboration, PRL 108 (2012) 042501
M. Agnello et al., FINUDA Collaboration, NPA 881 (2012) 269

FINUDA data have ambiguities. Complementary measurement is awaited.

DCX: Double Charge-eXchange
NCX: Non Charge-eXchnage

Studies of n-rich hypernuclei by DCX

- Experiments by the (stopped-K^-,π^+) reaction
  - **FINUDA**: M. Agnello et al. PRL 108 (2012) 042501
  - reported 3 candidate events of $^6_\Lambda$H production
  - measured production and decay to reduce background

$$^6Li(\text{stopped–}K^-,\pi^+)^6_\Lambda H \qquad ^6_\Lambda H \rightarrow {}^6He + \pi^-$$

$$BR(DCX,{}^6_\Lambda H)/BR(NCX) \approx 2\times10^{-3}/event$$

- Experiment by the (π^-,K^+) reaction
  - **KEK E521**: P.K. Saha et al. PRL 94 (2005) 052501
  - successfully produced $^{10}_\Lambda$Li $\quad ^{10}B(\pi^-,K^+)^{10}_\Lambda Li$
  - background free, only production was measured

$$\frac{d\sigma}{d\Omega}(DCX,{}^{10}_\Lambda Li) \approx 10nb/sr \qquad \frac{d\sigma}{d\Omega}(DCX)\bigg/\frac{d\sigma}{d\Omega}(NCX) \approx 10^{-3}$$

employed in E10 to make a measurement complementary with FINUDA

Production of neutron-rich Λ hypernuclei

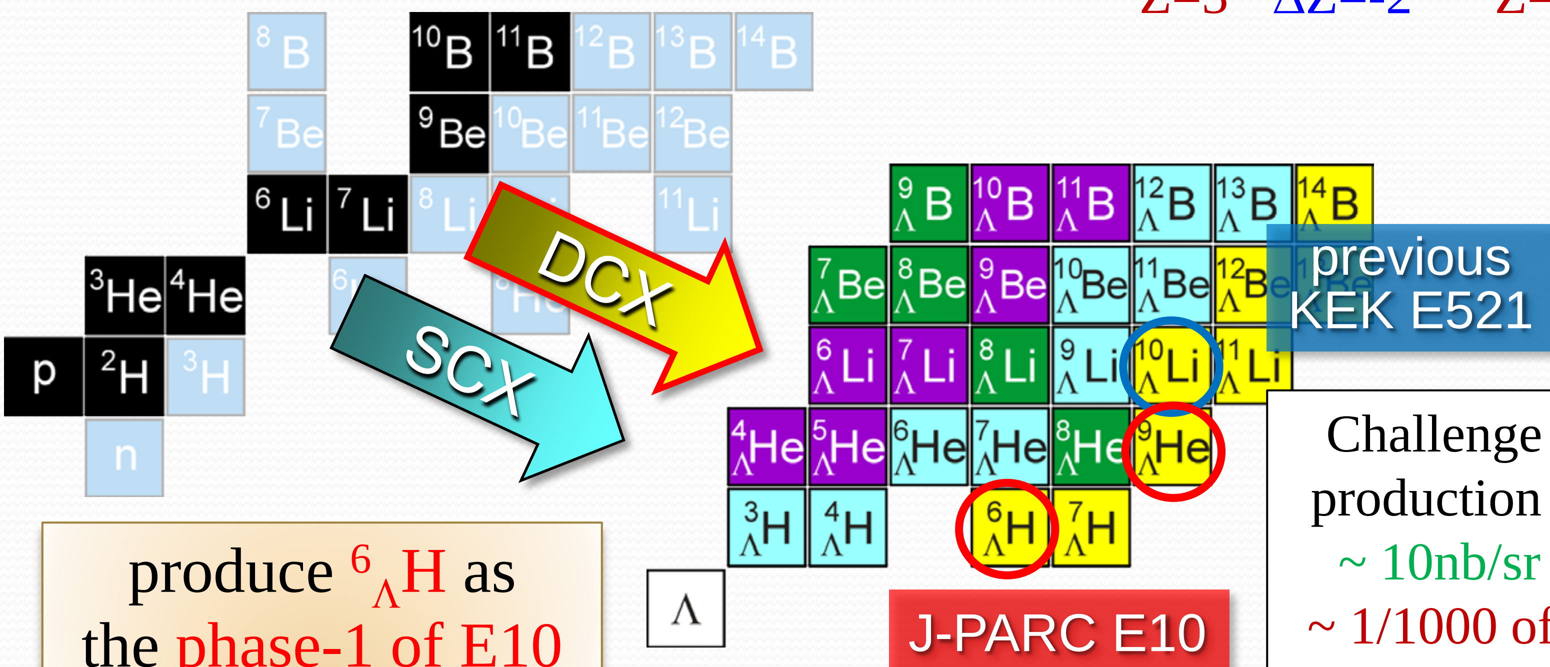
- How to produce in E10?
  - Employ the double charge-exchange (π^-,K^+) reaction

L. Majling, Nucl. Phys. A585 (1995) 211c

$$\pi^- + p + p \to K^+ + \Lambda + n$$

$$^{6}Li\left(\pi^-, K^+\right)\,^{6}_{\Lambda}H$$

Z=3 ΔZ=-2 Z=1

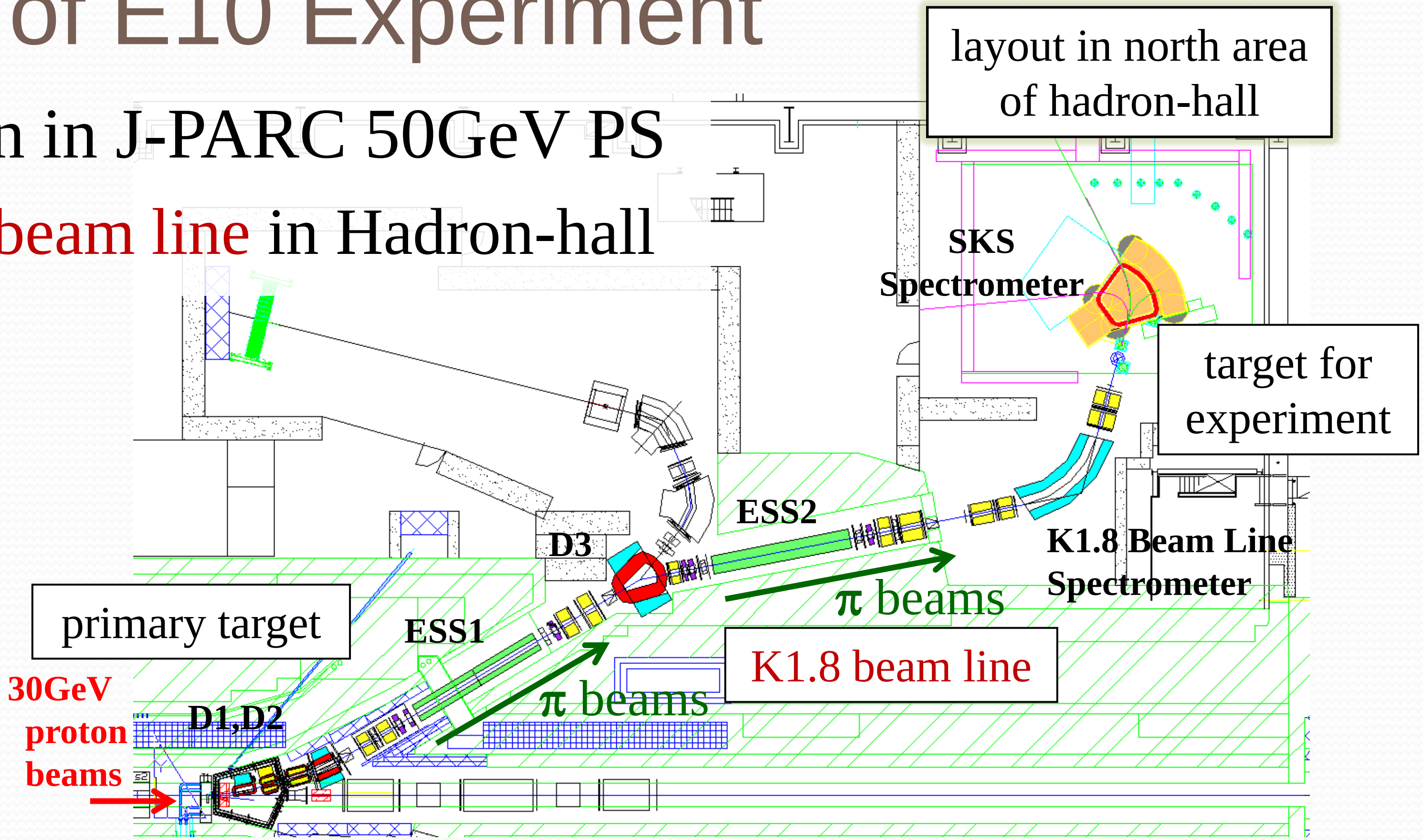


produce $^{6}_{\Lambda}$H as the phase-1 of E10

Challenge was the tiny production cross section
~ 10nb/sr ($^{10}_{\Lambda}$Li case)
~ 1/1000 of Non Charge-Exchange reaction

Design of E10 Experiment

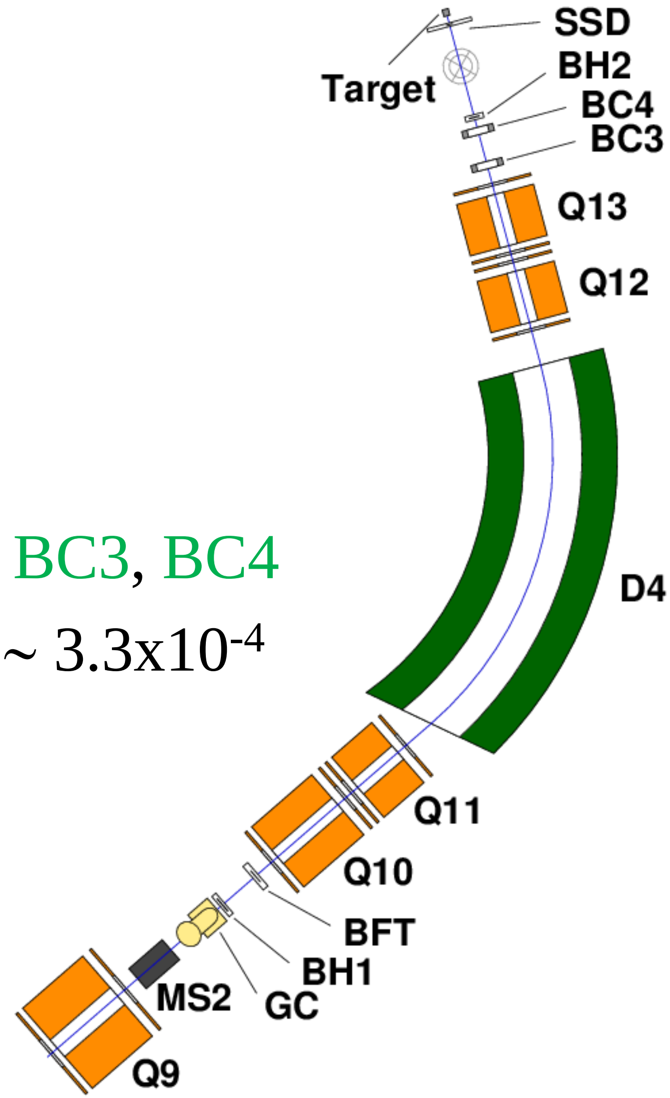
- Location in J-PARC 50GeV PS
  - K1.8 beam line in Hadron-hall



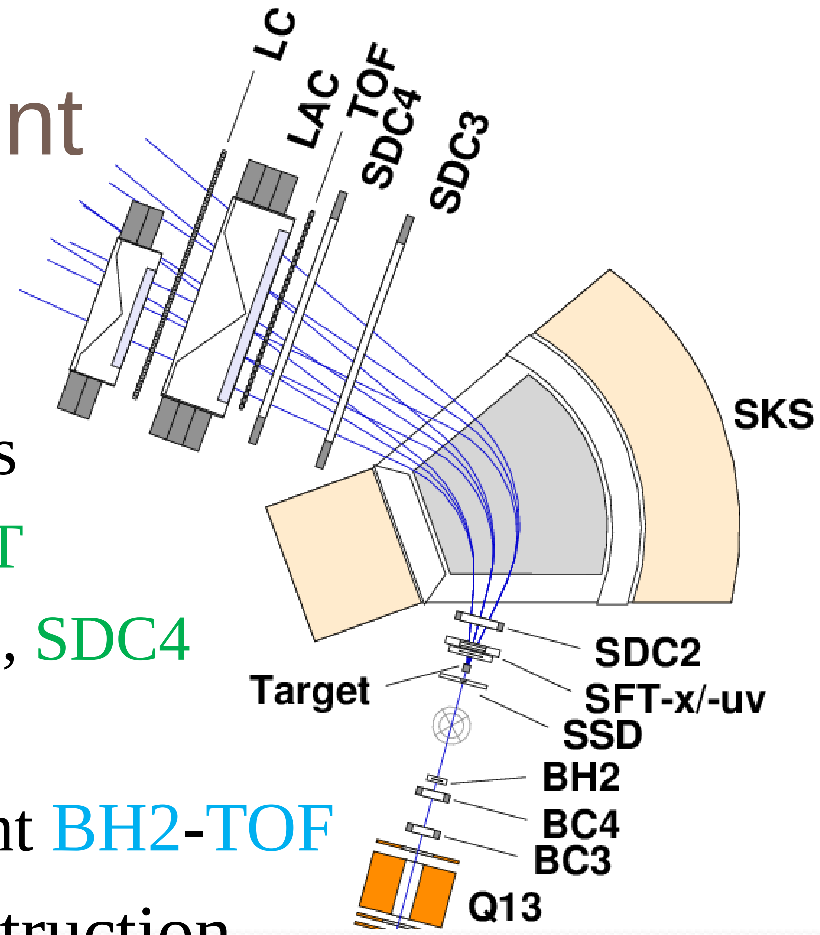
- Method
  - Missing mass spectroscopy for the ^{6}Li(π^-,K^+)X reaction
    - K1.8 beam line spectrometer: π^- beams at 1.2 GeV/c
    - SKS spectrometer: produced K^+ around 0.9 GeV/c

Setup of E10 experiment

- K1.8 beam line spectrometer
  - 1.2 GeV/c pion beams
  - Tracking of beam pions
    - Scintillating fiber tracker: BFT
    - Drift chambers (3mm wire pitch): BC3, BC4
    - 3rd order transfer matrix → dp/p ~ 3.3×10^{-4}
  - Trigger counters
    - Timing hodoscopes: BH1, BH2
- Key issue in E10 experiment
  - Handling of high rate pion beams
    - Typical beam rate: 12M - 14M/spill



Setup of E10 experiment



- SKS spectrometer
  - 0.9 GeV/c produced K^+
  - Tracking of scattered particles
    - Scintillating fiber tracker: SFT
    - Drift chambers: SDC2, SDC3, SDC4
    - $dp/p \sim 10^{-3}$, $d\Omega \sim 100$ msr
  - K^+ PID made by time-of-flight BH2-TOF
- (π^-,K^+) reaction vertex reconstruction
  - Silicon strip detector: SSD in front of the target
- Targets ($\sim$3.5 g/cm^2)
  - ^{6}Li for production runs, C and $(CH_2)_n$ for calibrations

Run conditions proposed and achieved

- Used high intensity pion beams as proposed
- 50% beamtime, analysis efficiency slightly lower

Run conditions	E10 proposal Values	E10 achievements Values
Pion beam momentum	1.2 GeV/c	1.2 GeV/c
Pion beam intensity	10M/spill	12-14M/spill
Beamtime for production run	500 hours	240 hours
Total number of pions	3T pions	1.4T pions
Target thickness (^{6}Li)	3.5 g/cm^2	3.5 g/cm^2
DCX cross section (assumed)	10 nb/sr	10 nb/sr
SKS acceptance	100 msr	100 msr
K decay loss	0.5	0.5
Analysis efficiency	0.5	0.3
Estimated $^6_\Lambda$H yield	265	90

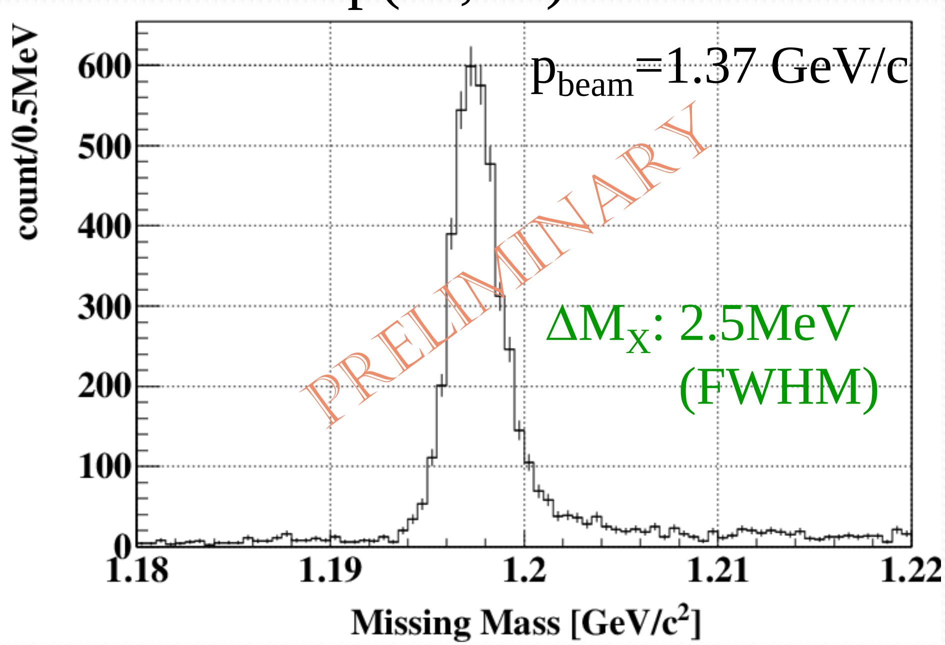
Sensitivity
~ 0.1 nb/sr

Calibration runs with Σ^- and Σ^+

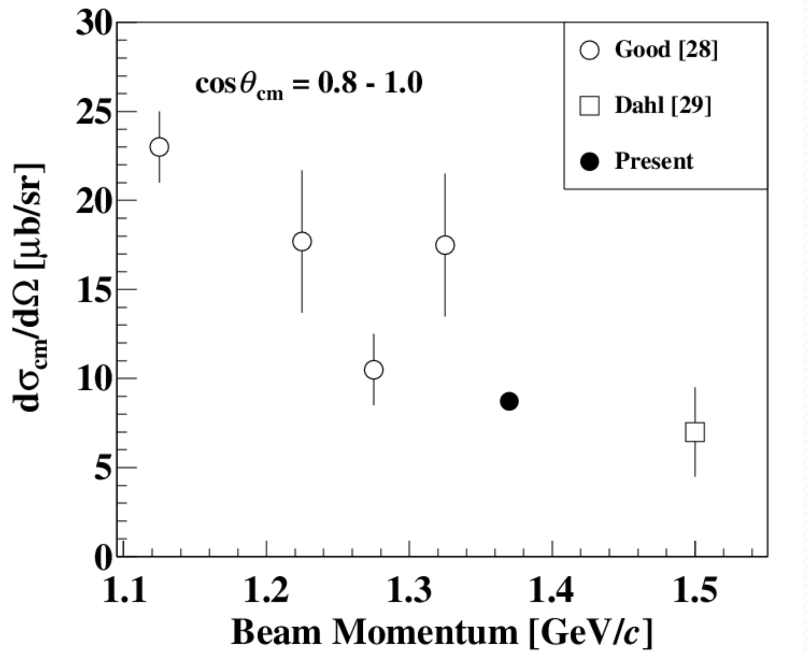
- Momentum calibrations of beam π^- and scattered K^+
  - Momentum adjusted: Σ^- and Σ^+ come to known mass
  - Cross section was compared with existing data

5 hours at 13M/spill

$p(\pi^-,K^+)\Sigma^-$



$p(\pi^-,K^+)\Sigma^-$



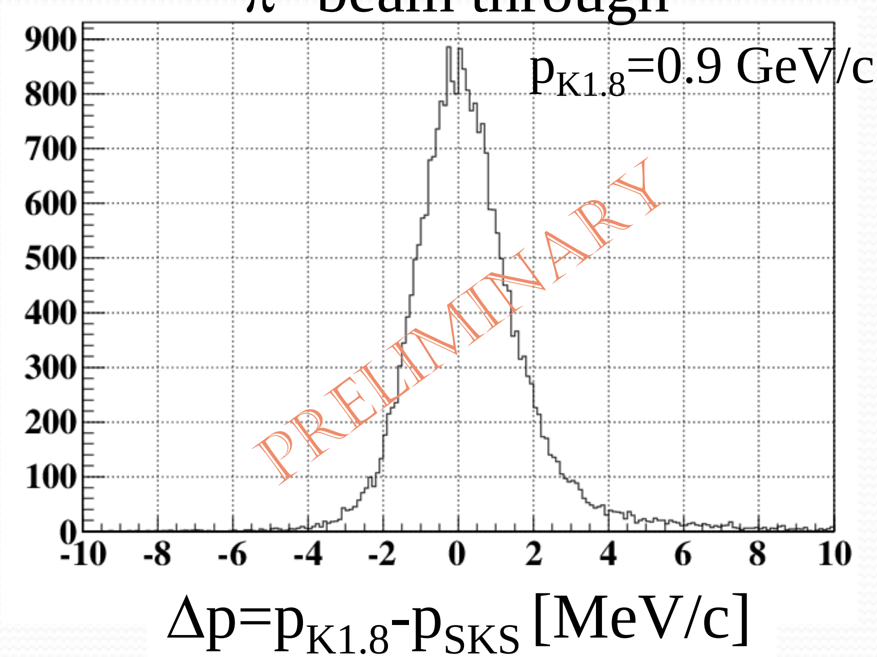
Systematic error and resolution

- Beam through runs at 0.8, 0.9, 1.0 and 1.2 GeV/c
  - Systematic error of beam momentum was 1.34 MeV/c
- Missing mass resolution was estimated by $^{12}{}_{\Lambda}C$

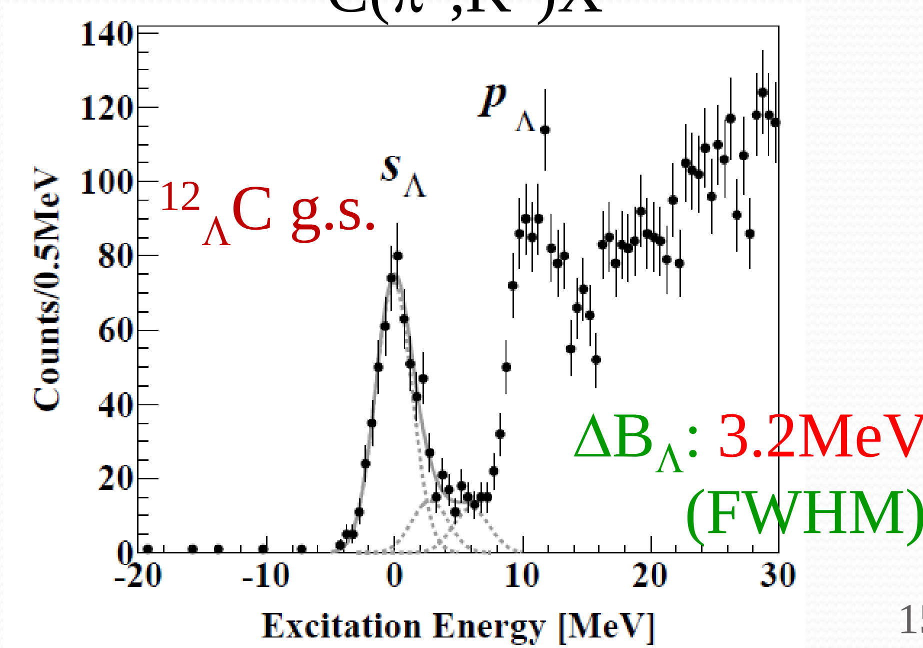
1 hour (8 settings)

13+6 hours at 4.1M/spill

π^+ beam through

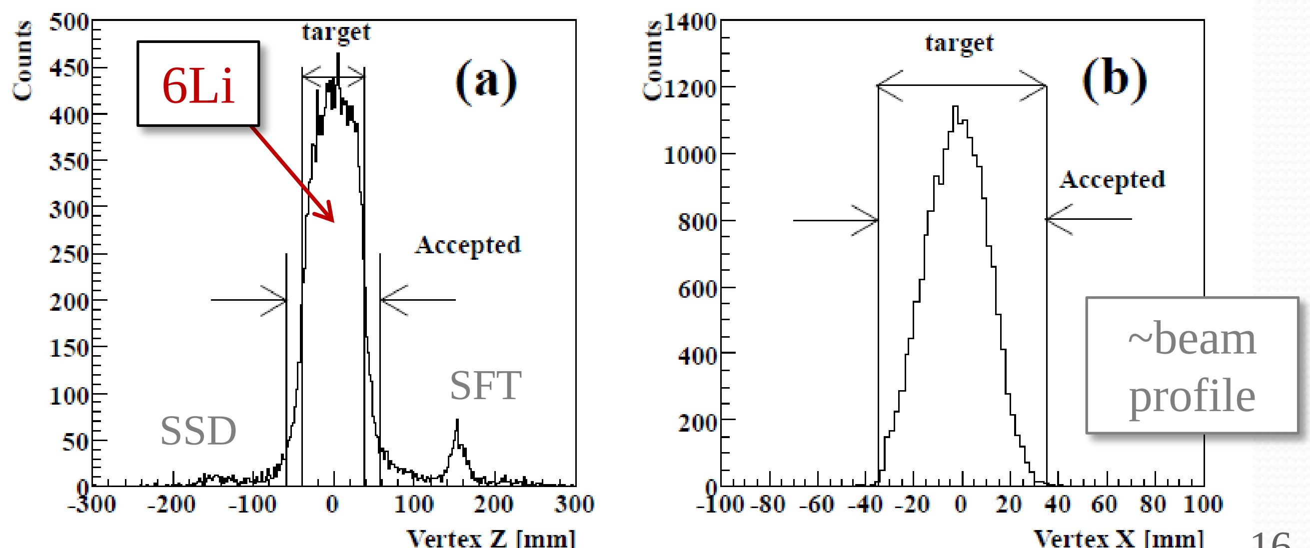


$^{12}C(\pi^+,K^+)X$



Results of production runs

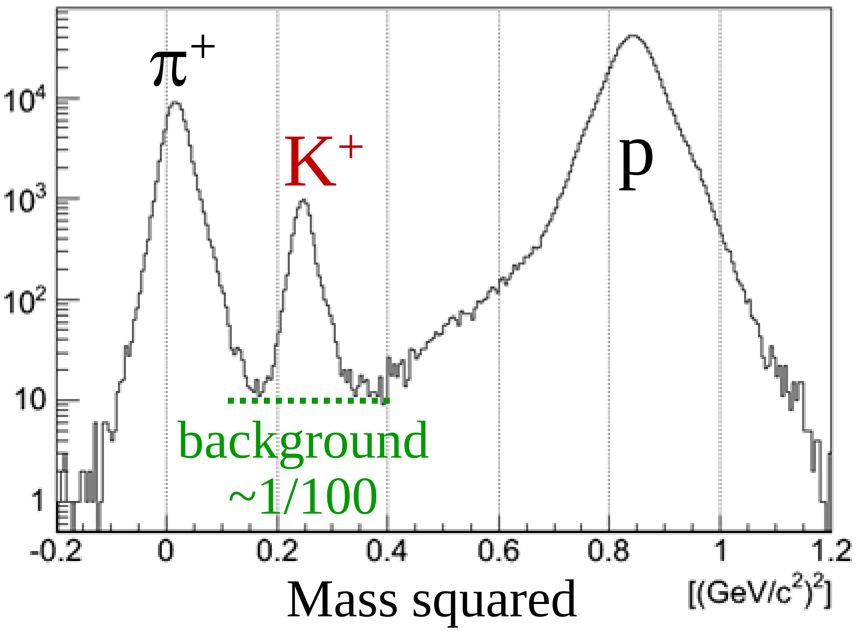
- Reaction vertex reconstruction
  - ^{6}Li target (95.54% enriched) packaged in dry Ar-gas
    - thickness: 3.5g/cm^2(77mm), cross section: $70^{W} \times 40^{H}$ mm^2
  - Vertex reconstruction and ^{6}Li target selection
    - cut values: Z 77+40mm, X 70mm, Y 40mm



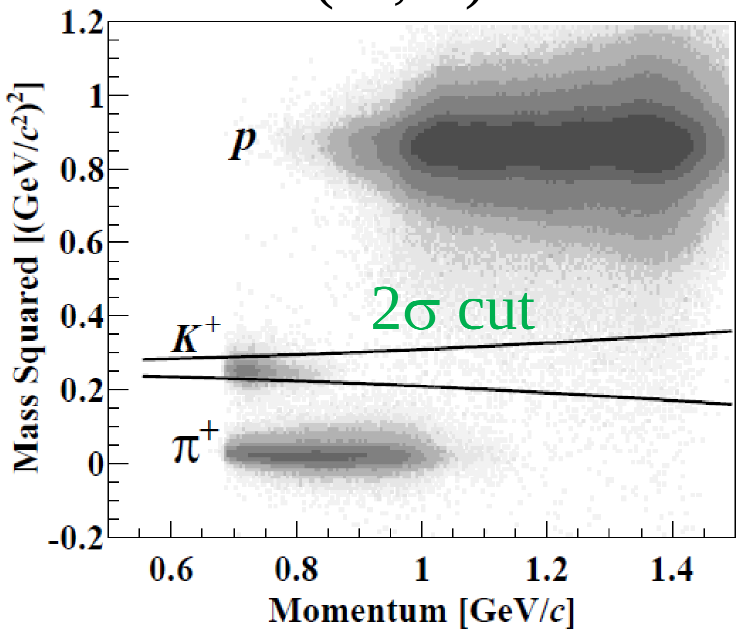
Results of production runs (2)

- PID of scattered K^+ is very important
  - No physics background. Background from miss-PID.
  - Current background level ~ 1/100
  - Momentum dependent selection of Kaon (2σ cut)

$^6Li(\pi^-,h^+)X$ (π^-,K^+) trigger, p<1.1GeV/c



$^6Li(\pi^-,h^+)X$



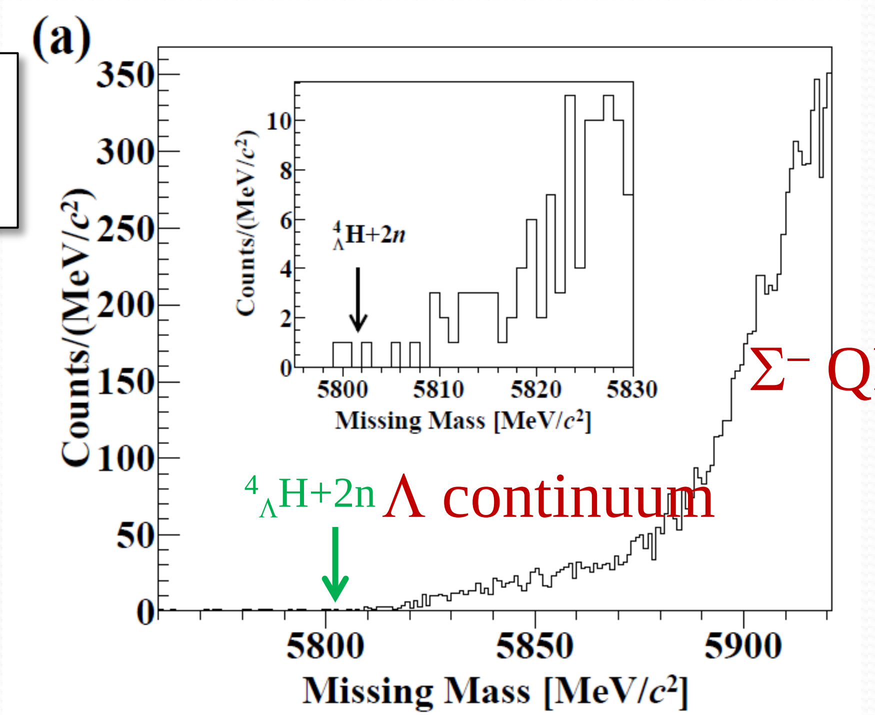
Results of production runs (3)

- Missing-mass spectrum of the ^{6}Li(π^{-},K^{+})X reaction
  - Systematic error of missing-mass 1.26 MeV/c^2
  - Tentative angle cut 2-14 degrees is applied
    - Same as KEK-E521 and SKS acceptance is well known

^{6}Li(π^{-},K^{+})X
θ_{LAB}=2-14 deg.

No clear peak of $^{6}_{\Lambda}$H production

Yield was extremely smaller than we expected



Results of production runs (4)

- Estimation of cross section upper-limit
  - Calculation of double differential cross section

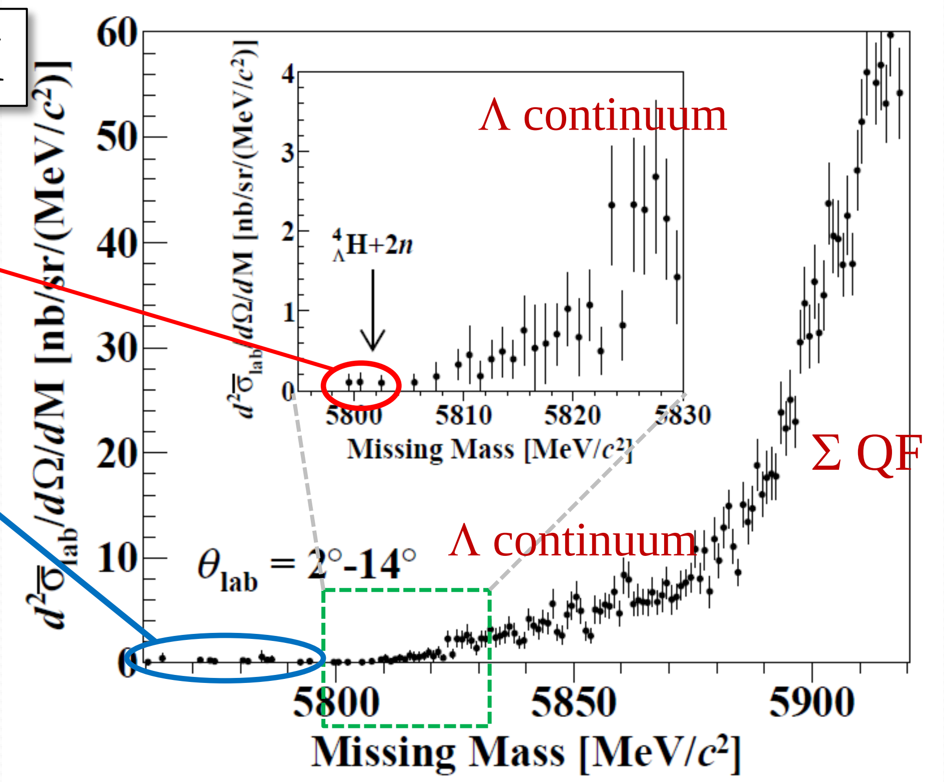
^{6}Li(π^-,K$^+$)X

3 events around $^{4}_{\Lambda}$H+2n threshold

Background due to miss-PID
0.39±0.05 event/(MeV/c^2)

Expected number of background is ~2 events

1 event ~ 0.18 nb/sr



- $d\sigma_{2^\circ\text{-}14^\circ}/d\Omega$ <1.2 nb/sr (90% confidence level)

Short summary of current status

- FINUDA data
  - 3 candidate events: $BR(DCX, {}^{6}_{\Lambda}H) / BR(NCX) \approx 6\times10^{-3}$
  - Need reaction processes effective only for stopped-K$^-$
    - e.g. $K^- pp \rightarrow \Lambda^* p \left(\Sigma^{0*} p\right) \rightarrow \pi^+ \Lambda n$ (just my personal guess)
- E10 data
  - Upper-limit for ${}^{6}_{\Lambda}$H: $\frac{d\sigma}{d\Omega}(DCX, {}^{6}_{\Lambda}H) \Big/ \frac{d\sigma}{d\Omega}(NCX) < 10^{-4}$
  - Can we interpret the strong suppression by the reaction mechanism or by the structure of ${}^{6}_{\Lambda}$H?
  - Need theoretical estimations for further discussions.
- E521 data
  - ${}^{10}_{\Lambda}$Li cross section: $\frac{d\sigma}{d\Omega}(DCX, {}^{10}_{\Lambda}Li) \Big/ \frac{d\sigma}{d\Omega}(NCX) \approx 10^{-3}$

Summary

- Phase-1 beamtime of J-PARC E10 experiment
  - Run at high beam intensity as proposed: 10M-12M/spill
  - 1.4 T pion beams on target (about 50% of proposal)
- All calibration runs were done ($\Sigma^{\pm}$ and ${}^{12}_{\Lambda}C$)
  - Systematic error of missing-mass scale is 1.26 MeV/c^2
  - Missing-mass resolution is 3.2 MeV/c^2 (FWHM)
- Analysis of ${}^{6}_{\Lambda}H$ production data was done
  - No clear peak was observed in the threshold region
  - Cross section upper-limit is 1.2 nb/sr (90% C.L.)
  - Studies are still in progress to improve the sensitivity