The result of search for ${}^{6}_{\Lambda}$H via the ^{6}Li(π^-, K^+) reaction in J-PARC E10

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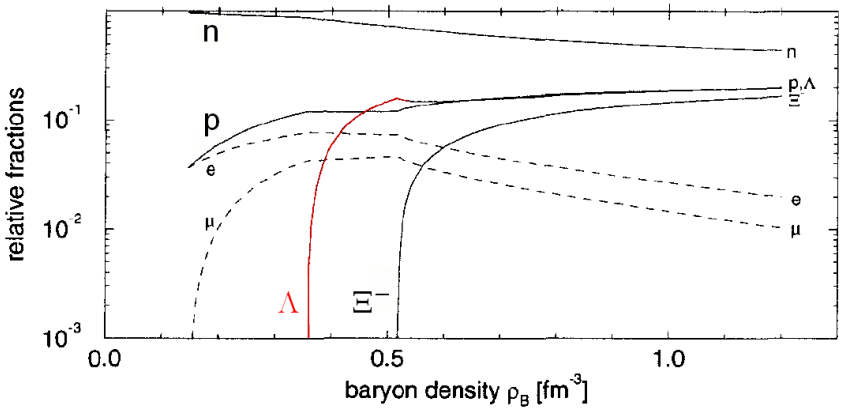
For the J-PARC E10 collaboration.

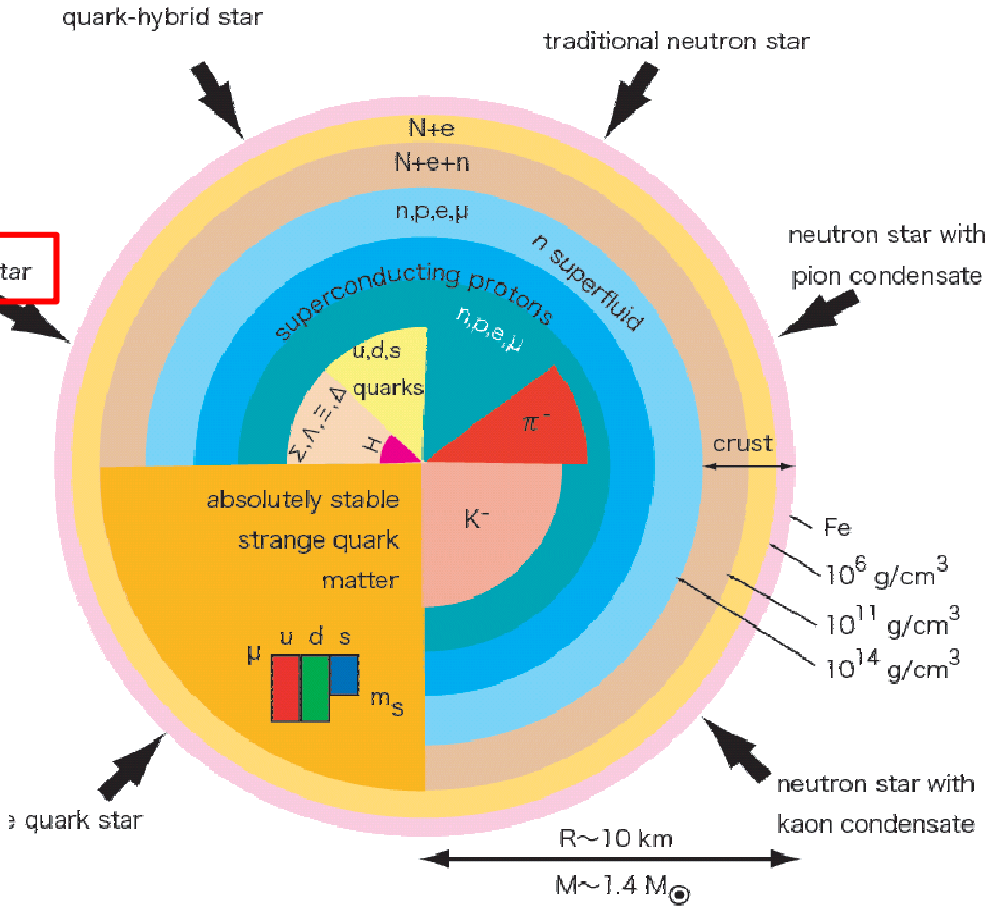
Outline

- Introduction
- J-PARC E10 experiment
- Latest analysis result
- Summary

Physics motivation – Neutron star and Hyperons -

Hyperon mixing in inner core of neutron star.





Shmuel Balberg, Avraham Gal (Hebrew U.). Apr 1997. 38 pp. Published in Nucl.Phys. A625 (1997) 435-472

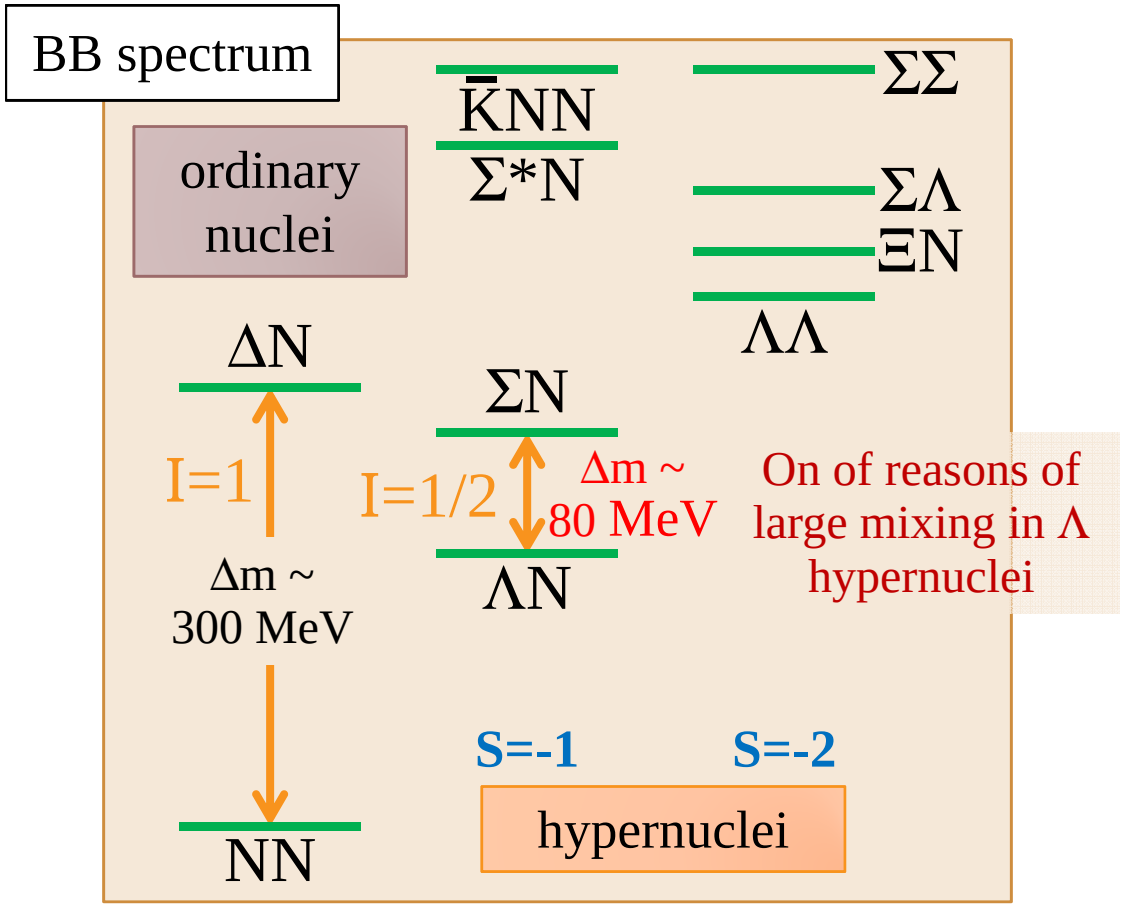
Possible internal structures of neutron star

Physics motivation

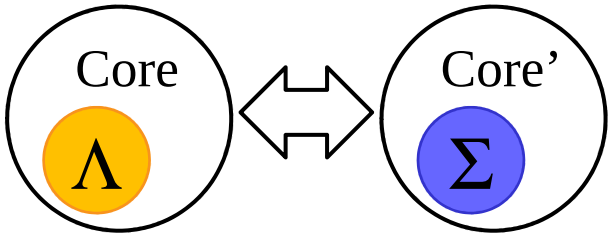
-ΛN-ΣN mixing in n-rich Λ hypernuclei

Large contribution of ΛN-ΣN mixing is expected

- B.F. Gibson et al. PR C6 (1972) 741



ΛN-ΣN mixing in Λ hypernuclei

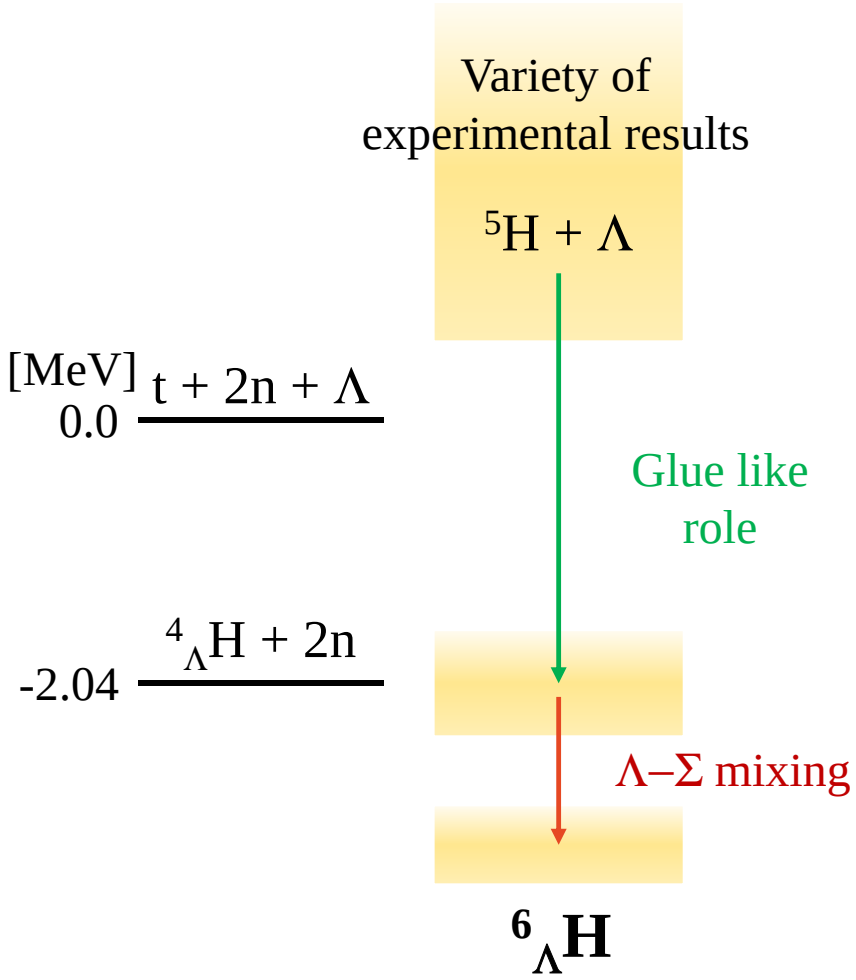


Large overlap in nucleon part only if $N \neq Z$ ($I_{core} \neq 0$)
Pauli blocking may be small

Core nucleus is a buffer of isospin

How large ΛN-ΣN mixing in neutron-rich Λ hypernuclei?

Physics motivation – $^{6}_{\Lambda}$H neutron-rich hypernucleus



Production of
the extremely neutron-rich hypernuclei.

- The glue like role of the Λ particle in nuclei could stabilize the unbound ^{5}H system.

Λ-Σ mixing in the neutron-excess environment.

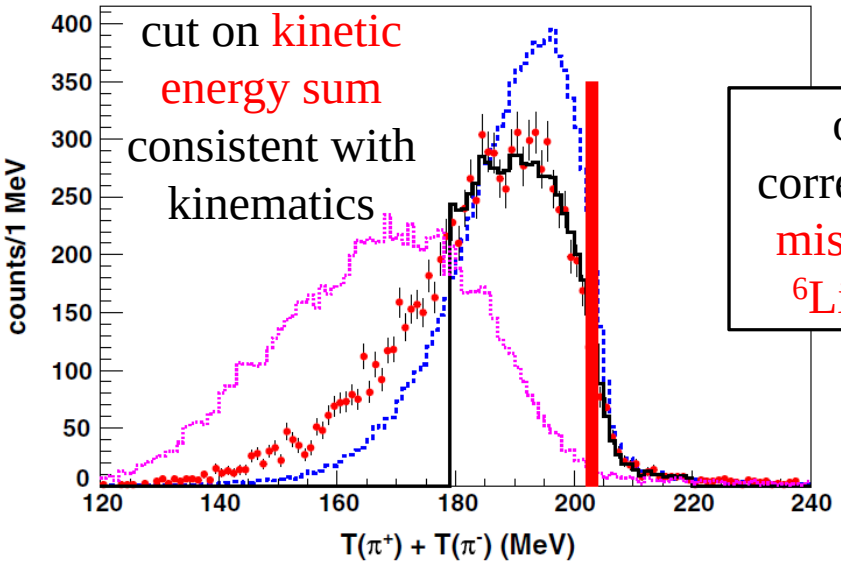
- The coupling effect is expected to be enhanced in the neutron-excess environment by summed up coherently.

${}^{6}_{\Lambda}$H search by FINUDA collaboration

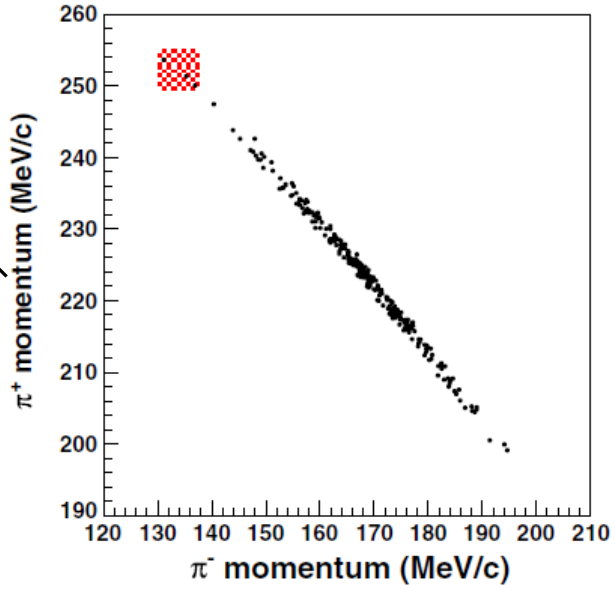
$$ {}^{6}\mathrm{Li}(K^{-}_{\mathrm{stop}},\pi^{+})\,{}^{6}_{\Lambda}\mathrm{H} \qquad {}^{6}_{\Lambda}\mathrm{H}\rightarrow {}^{6}\mathrm{He}+\pi^{-} $$

FINUDA: M. Agnello et al. PRL 108 (2012) 042501

- Study of the ^{6}Li(K^{-}_{stop},$\pi^{+}\pi^{-}$) reaction

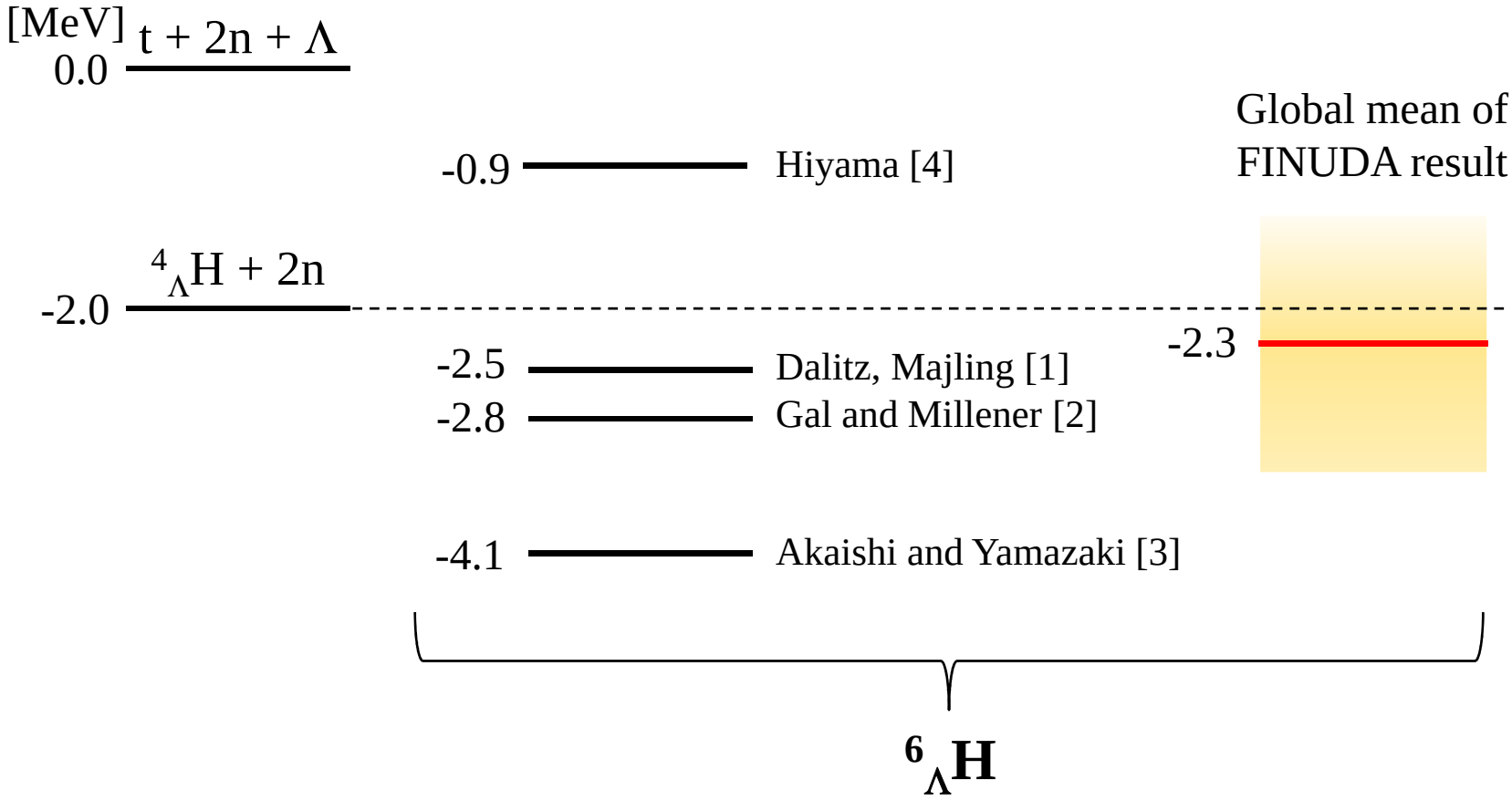


one to one correspondence to missing-mass of ^{6}Li(K^{-}_{stop},π^{+})X



Three candidates of ${}^{6}_{\Lambda}$H

Present theoretical expectation and result



[1]. R. H. Dalitz and R. Levi-Setti, Nuovo Cimento 30, 489 (1963); L. Majling, Nucl. Phys. A585, 211c (1995).

[2] A. Gal and D.J. Millener, Physics Letters B 725 (2013) 445–450

[3] Y. Akaishi and T. Yamazaki, Franscati Phy. Ser. XVI, 59 (1999).

[4] E. Hiyama et al., Nuclear Physics A 908 (2013) 29–39

J-PARC E10 experiment

J-PARC E10 Experiment

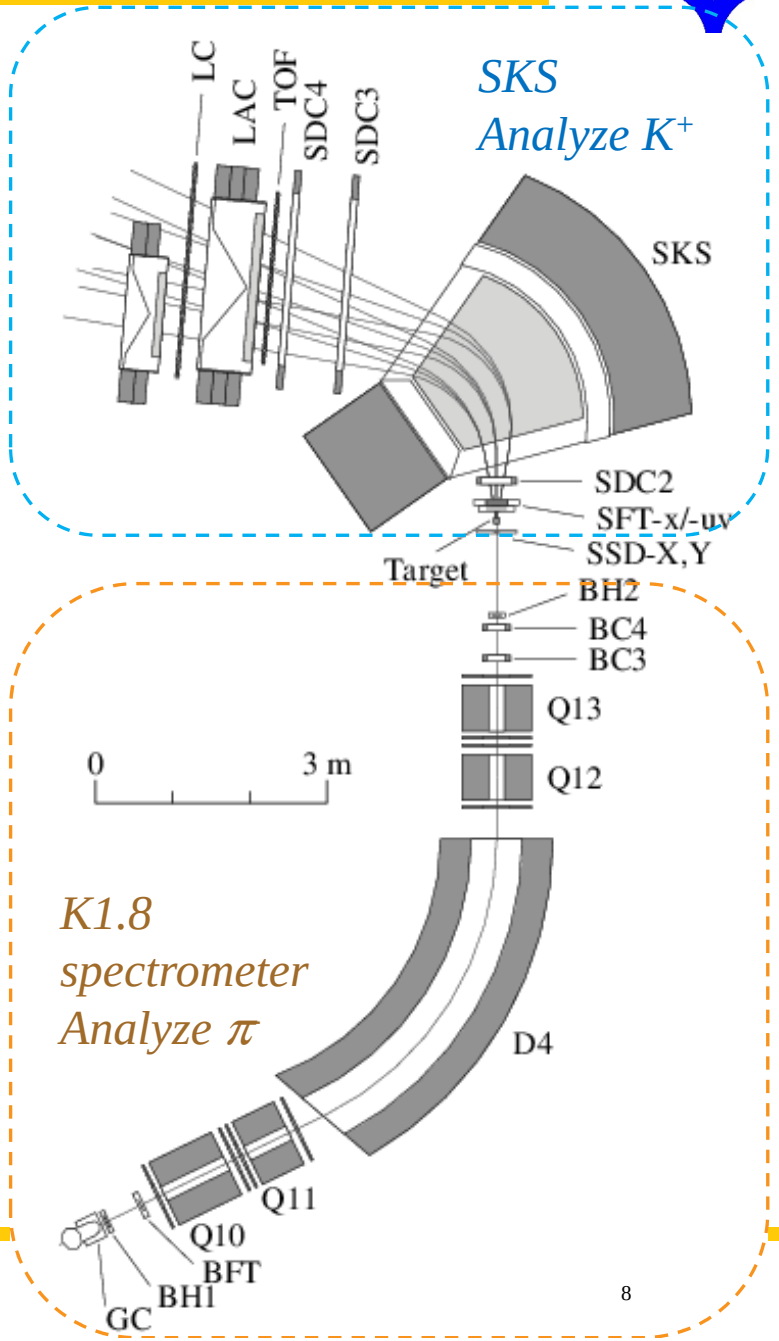
Missing mass spectroscopy at J-PARC K1.8
carried out in 2012 and 2013

The ^{6}Li(π^-, K^+)X reaction @ 1.2 GeV/c
with ^{6}Li target (3.5 g/cm^2, 95.54% enriched).

Expected production cross section of $^{6}_{\Lambda}$H hypernucleus.

- 10 nb/sr. (From KEK-PS E521)

A large number of pion beams (3×10^{12}) using
10 M/spill beam (spill length = 2 s.)



Data summary

	Reaction	Beam mom (GeV/c)	Target
Production run	(π^-, K^+)	1.2	^{6}Li (3.5 g/cm2, 95.54% enriched)
$^{12}_{\Lambda}$C production	(π^+, K^+)	1.2	Graphite (3.6 g/cm2)
Σ^- production	(π^-, K^+)	1.37	Polyethylene (3.4 g/cm2)
Σ^+ production	(π^+, K^+)	1.37	Polyethylene (3.4 g/cm2)

Production run

- Finally, the effective number of pions were 1.4×10^{12} in 13 days beam time using 10 - 12 M/spill beam.

$^{12}_{\Lambda}$C production

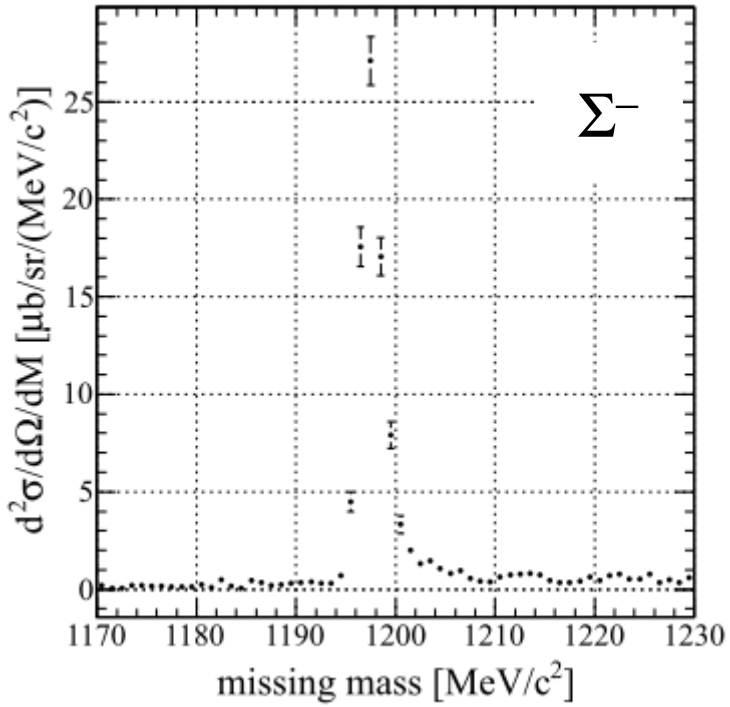
- Estimate missing-mass resolution.

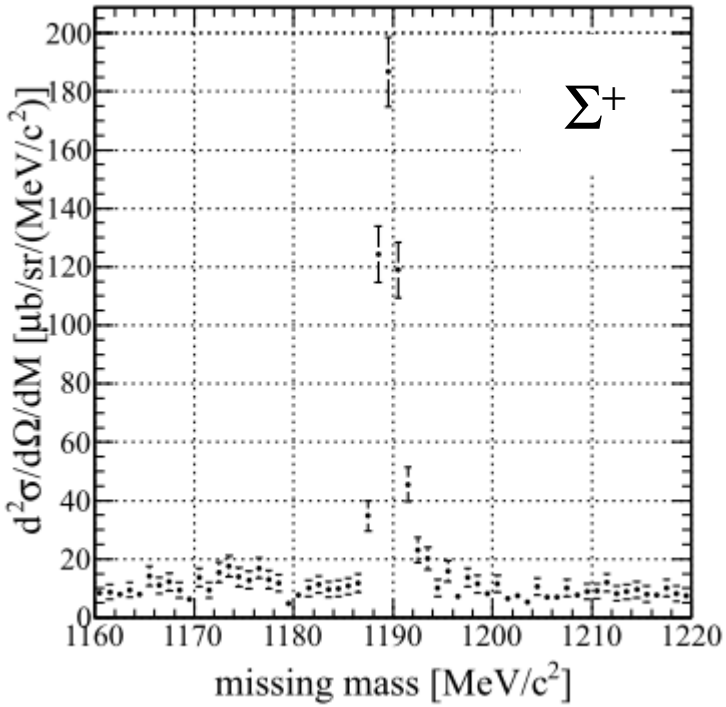
$\Sigma^{+/-}$ production

- Calibrate momentum.
- Confirm correctness of our analysis by comparing with the past experimental data.

Σ^-/Σ^+ analysis

Missing mass spectrum of $\pi^{\pm} + p \rightarrow K^+ + X$ reactions

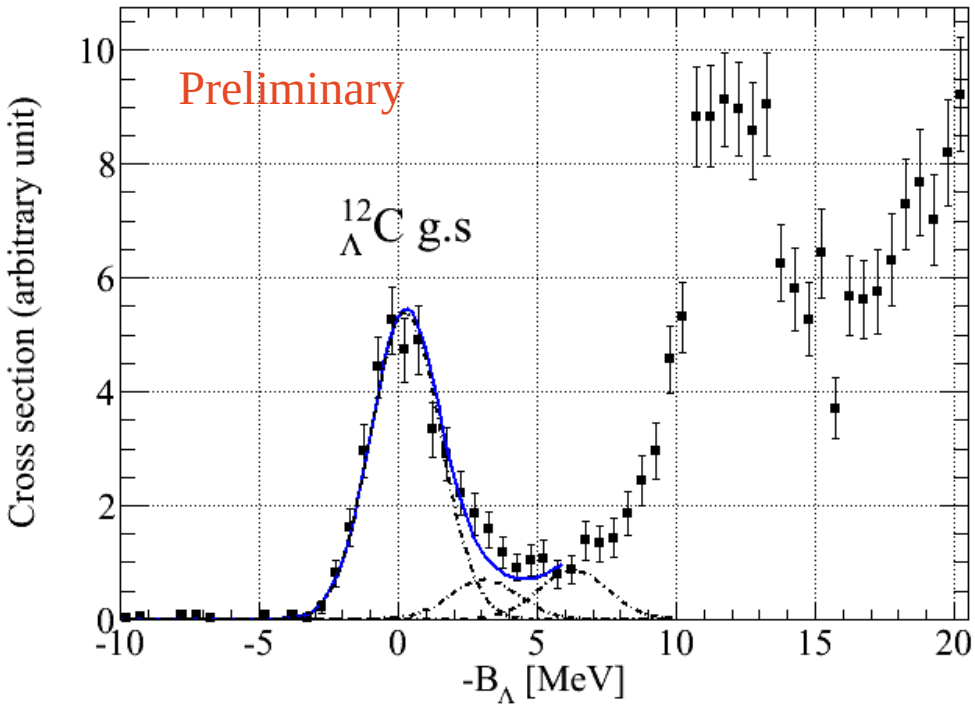




Beam and scattered particles momenta were calibrated by masses of $\Sigma^{\pm}$.
Present missing-mass uncertainty around bound state of ${}^{6}_{\Lambda}\mathrm{H}$ was 350 keV/c^2

$^{12}_{\Lambda}$C analysis

$^{12}_{\Lambda}$C spectrum and fitting functions



The spectrum was fitted by 3 Gaussian functions.

Missing mass resolution

- 2.9 ±0.2 MeV (FWHM)

The bound state of $^{6}_{\Lambda}$H was searched with this missing mass resolution.

Latest analysis results of production run

^{6}Li(π^-, K^+) event selection

π^- beam selection

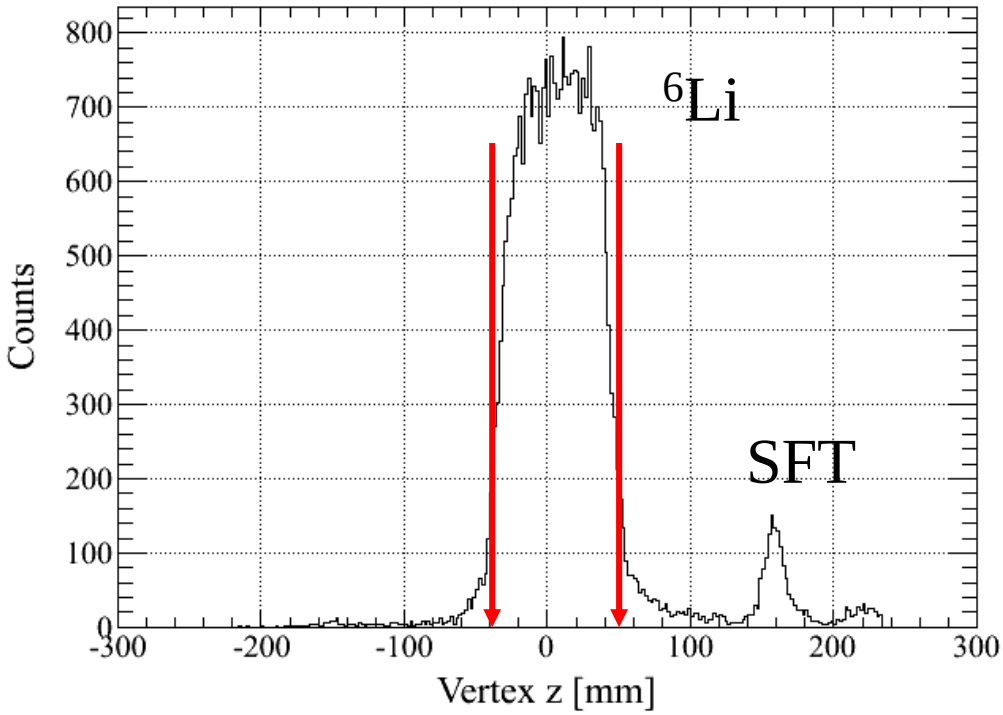
- Beam π^- were already well separated by double ESSs in the K1.8 beam line.

K^+ selection

- M^2 distribution
- dE/dx distribution of TOF counter

Vertex selection

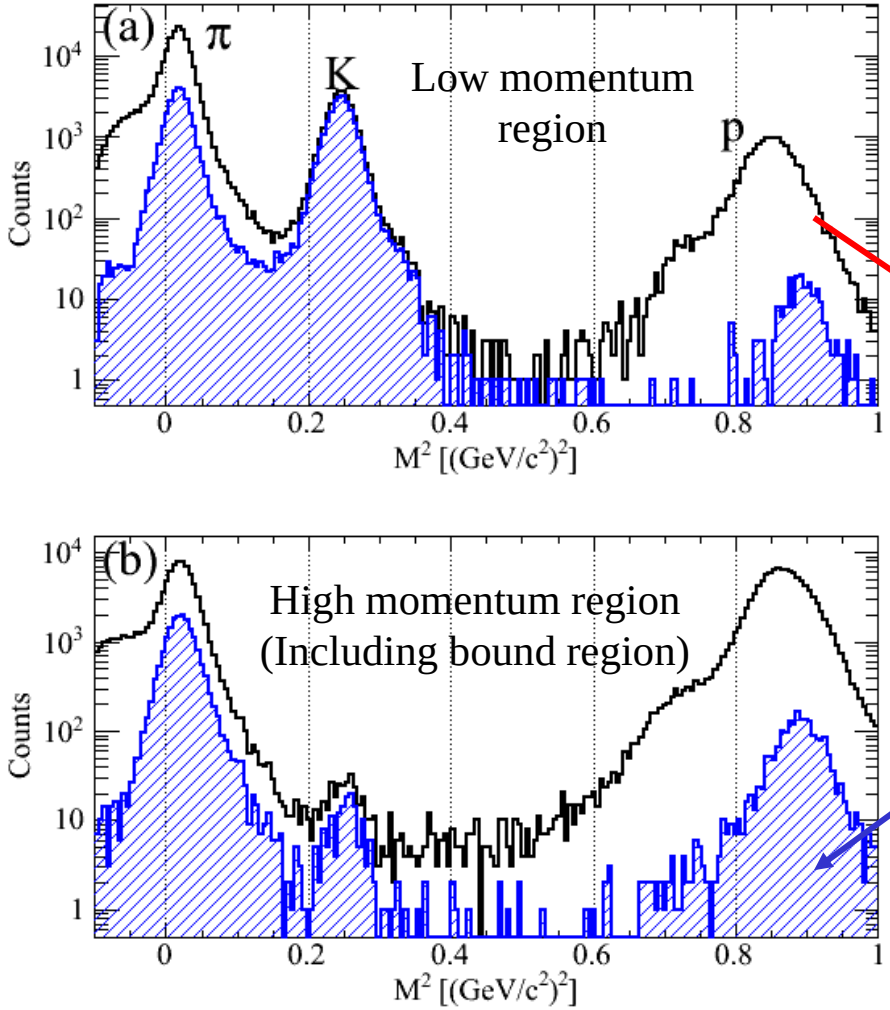
Vertex distribution along with the beam axis



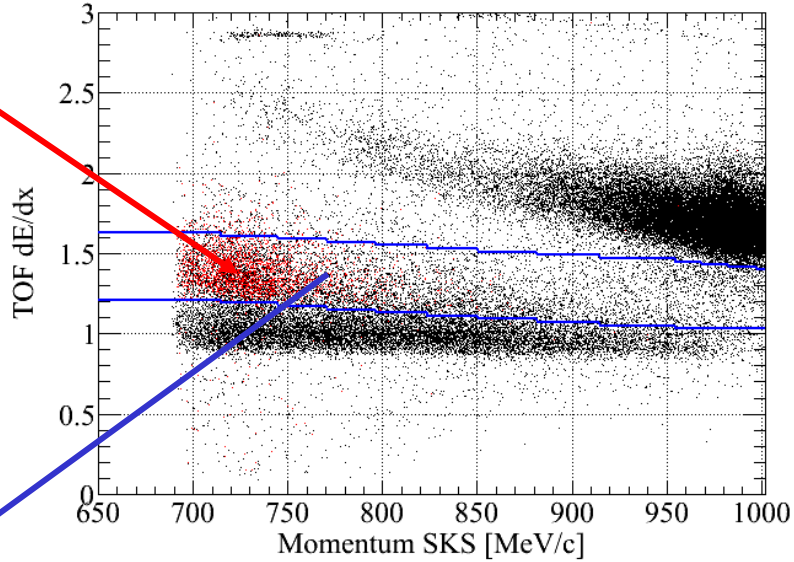
Actual target thickness $\pm$5 mm
were selected as ^{6}Li target.

^{6}Li(π^-, K^+) event selection

M^2 distribution of scattered particles



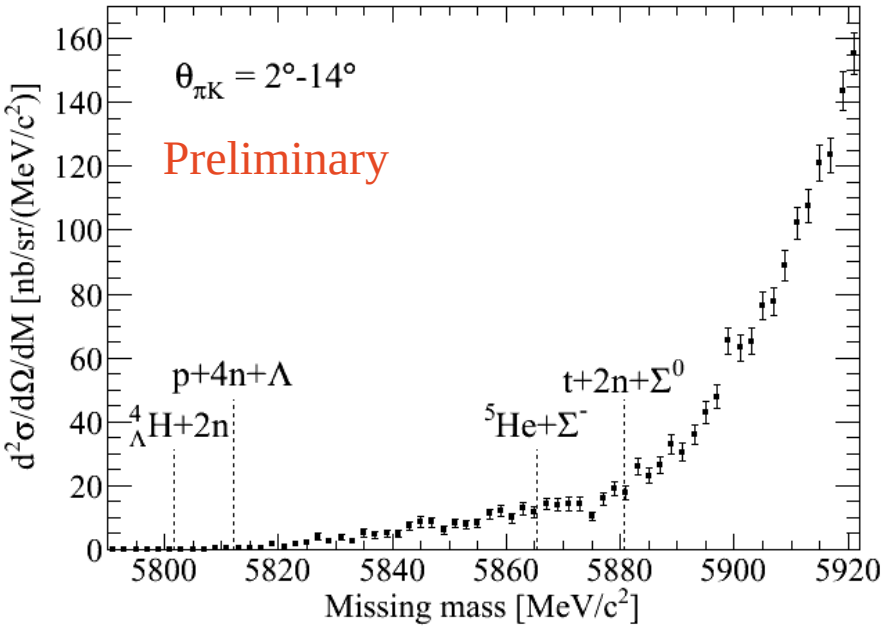
dE/dx distribution of TOF counter



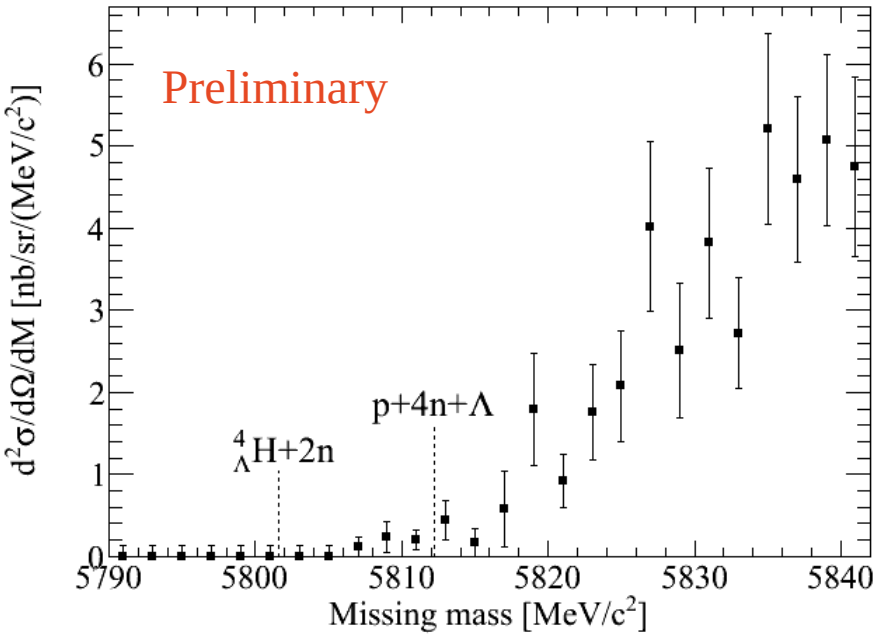
Red events were selected by M^2.
dE/dx were selected according to blue lines

Production cross section of ^{6}Li(π^-, K^+)X reaction

Production cross section of ^{6}Li(π^-, K^+)X reaction



Production cross section of ^{6}Li(π^-, K^+)X reaction (Zoom up)



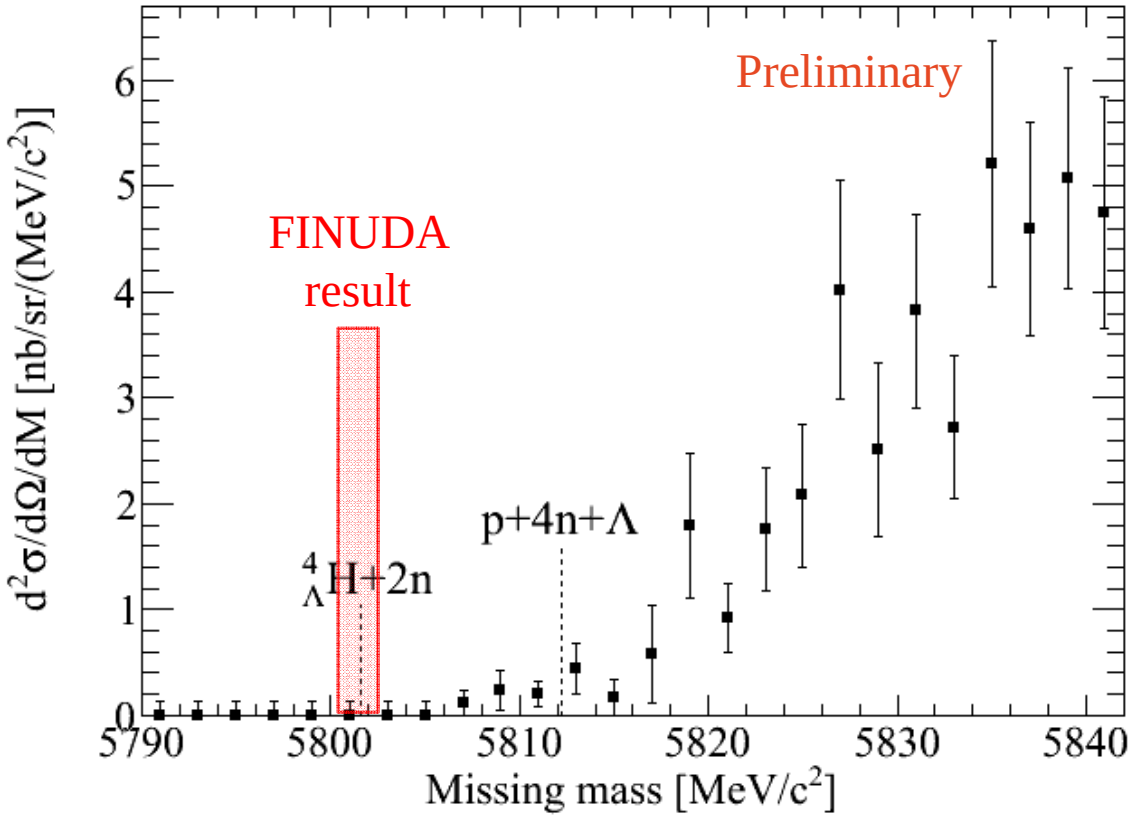
No event was seen below the $^{4}_{\Lambda}$H+2n threshold

Upper limit

0.56 nb/sr (90% C.L.)

Production cross section of ^{6}Li(π^-, K^+)X reaction

Production cross section of ^{6}Li(π^-, K^+)X reaction (Zoom up)



- The last event we observed was roughly 4 MeV far from the FINUDA result.
- The present upper limit was 20 times smaller than our expectation. Quite difficult to produce the $^{6}_{\Lambda}$H hyperncleus by this experimental method.
- On the other hand, several events were seen between $^{4}_{\Lambda}$H+2n and p+4n+Λ threshold. Some excited states may exist, but at least 10 times statistics is necessary to observe them.

Summary

- The J-PARC E10 experiment was proposed to produce the quite neutron-rich Λ hypernuclei, in which the property of the ΛN (ΛNN) interaction should be enhanced, via the (π^-, K^+) reaction.

- The E10 experiment was carried out in 2012 and 2013. The ^{6}Li target (3.5 g/cm2, 95.54% enriched) was irradiated with the 1.4x10^{12} pion beams in total.

- We searched the $^6_\Lambda$H bound state with the missing-mass resolution of 2.9 MeV/c^2 (FWHM) and the missing-mass scale uncertainty of 350 keV/c^2.

- **We obtained upper limit of 0.56 nb/sr (90% C.L).**
- **This is roughly 20 times smaller than our expectation.**

Back up

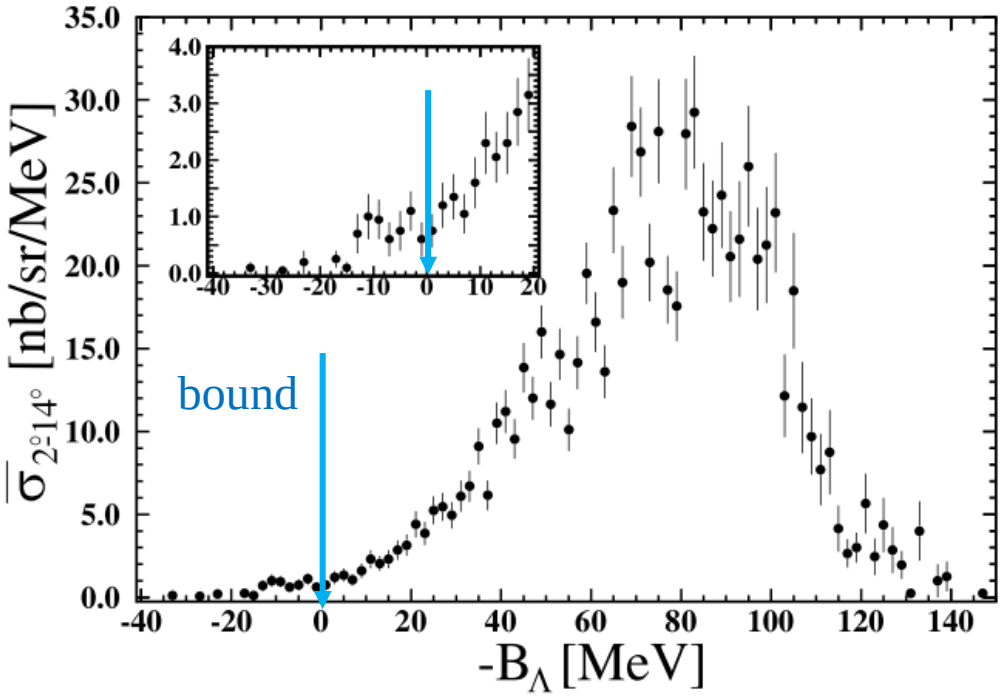
Production via the double-charge exchange reaction

The KEK-PS E521 experiment

$^{10}_{\Lambda}$Li production via the ^{10}B(π^-, K^+)X reaction at 1.05 and 1.20 GeV/c.

The (π^-, K^+) reaction is suitable to produce the hypernuclei
with quite small cross section because of its back ground free property.

The production of the neutron-rich hypernucleus was observed, but no peak was seen.

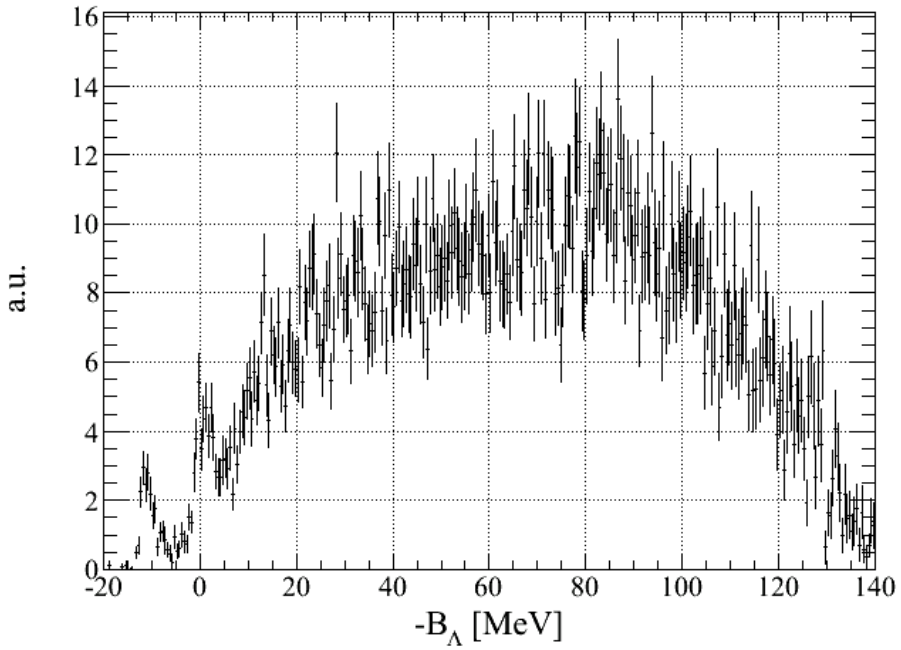


Integrated cross section
of bound region
11.3 ± 1.9 nb/sr

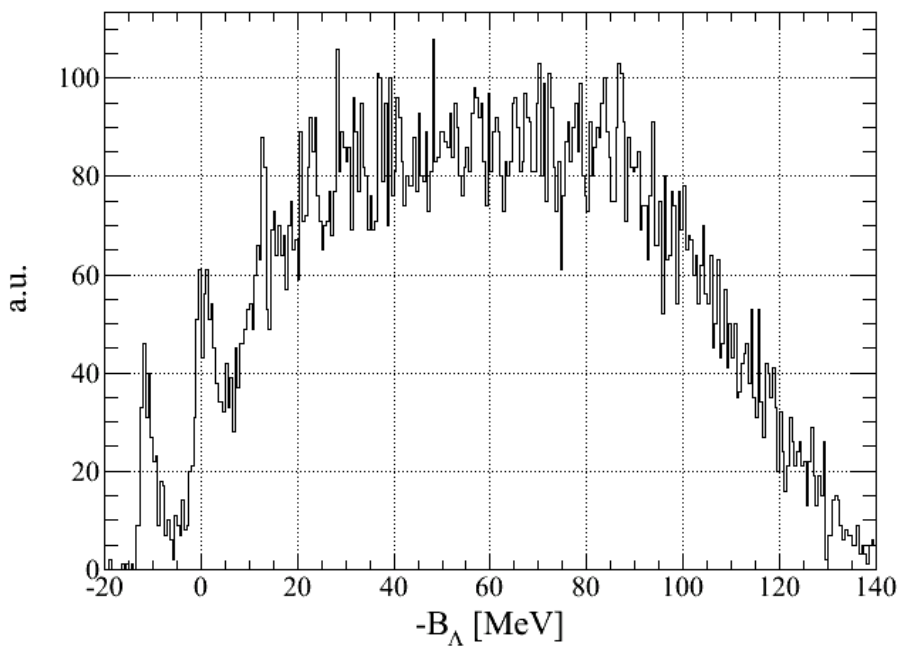
[P. K. Saha, et al., PRL 94 (2005) 052502.]

$^{12}_{\Lambda}$C analysis

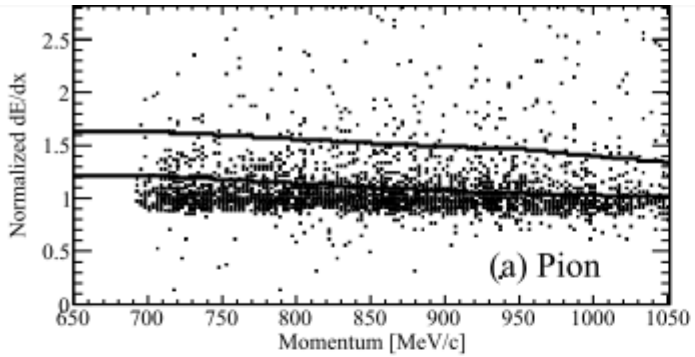
Relative cross section base
$^{12}_{\Lambda}$C spectrum

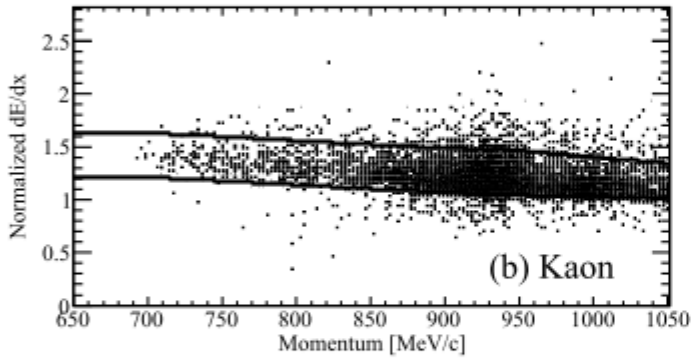


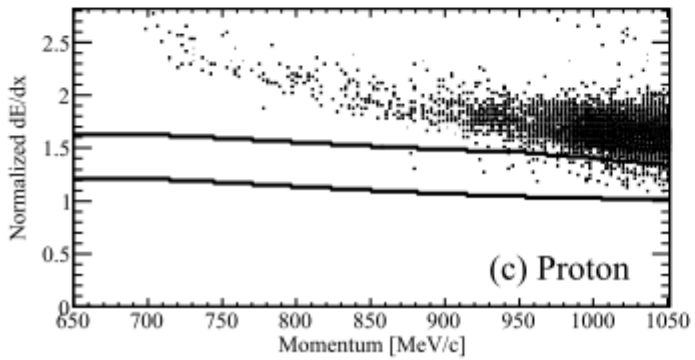
Count base
$^{12}_{\Lambda}$C spectrum



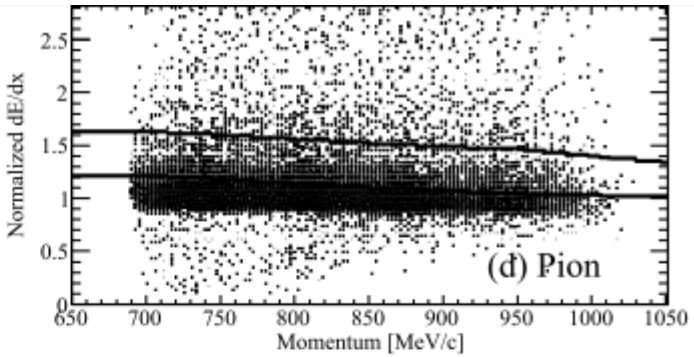
Σ^+ production data

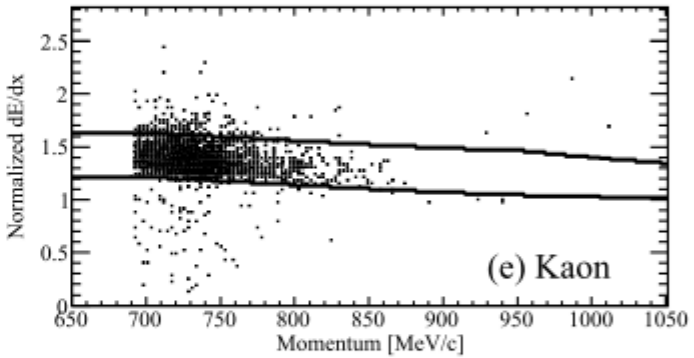


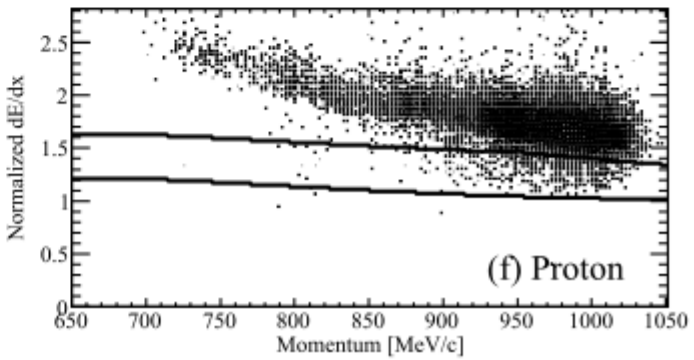




^{6}Li data

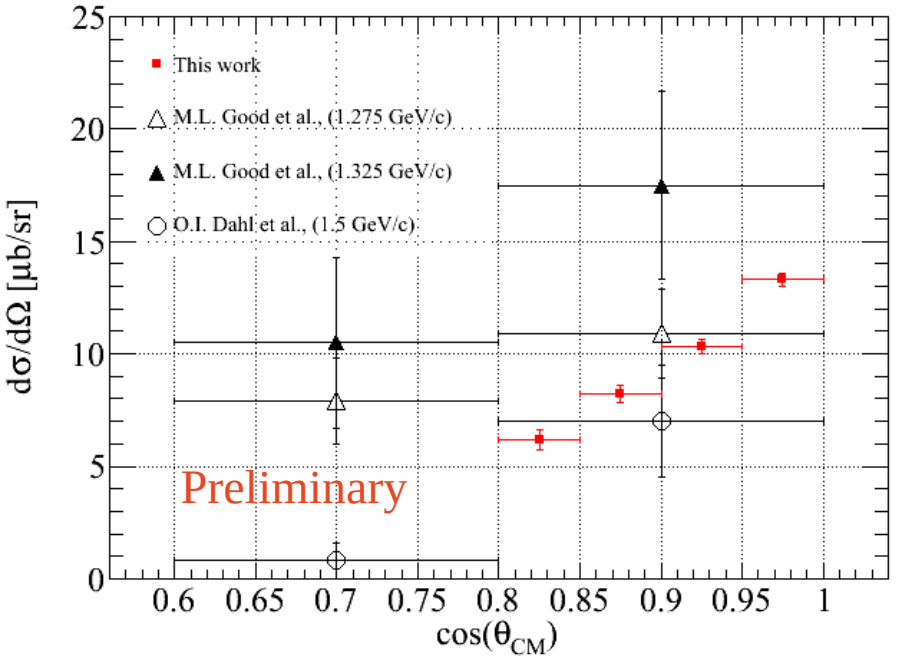




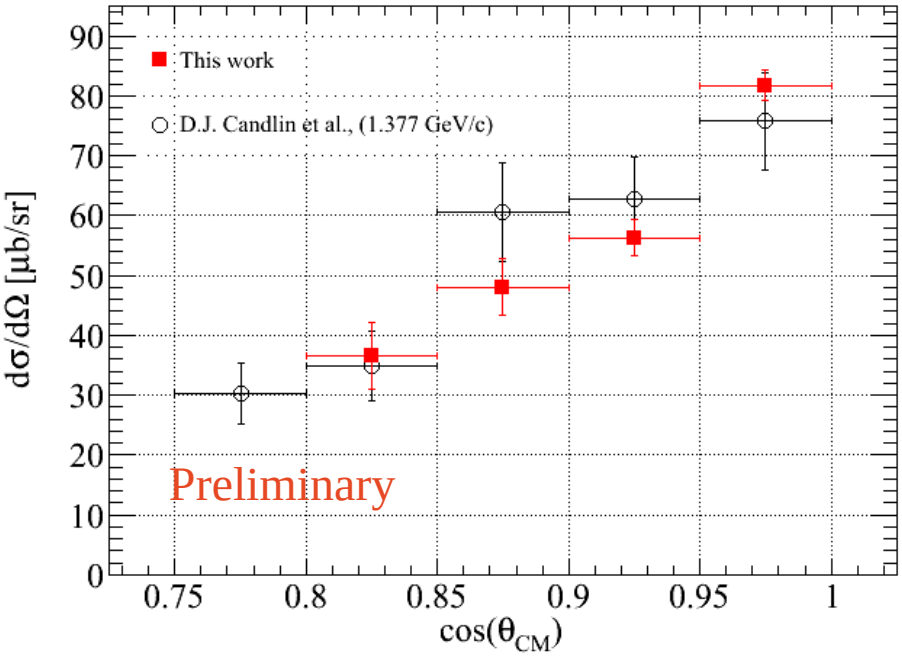


Σ^-/Σ^+ analysis

Angular distribution of
Σ^- production (2 – 14 deg (Lab.))

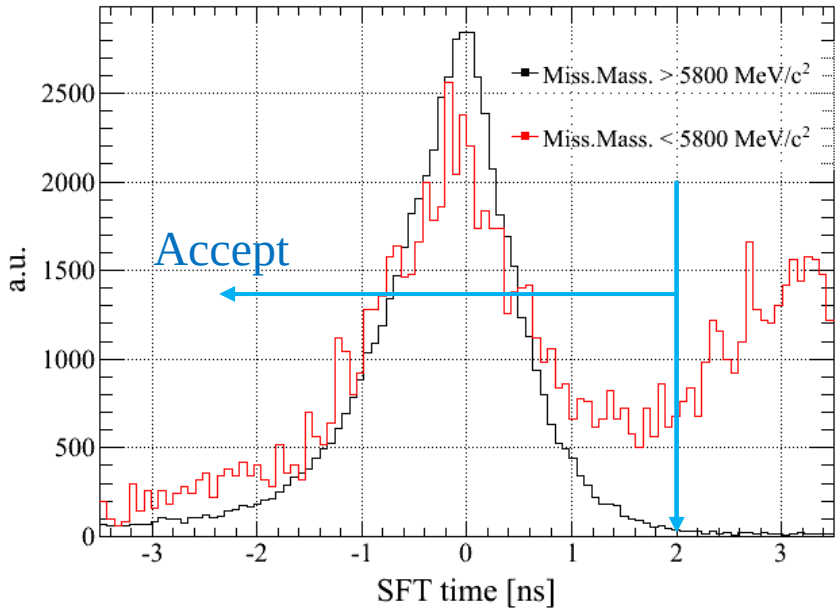


Angular distribution of
Σ^+ production (2 – 14 deg (Lab.))



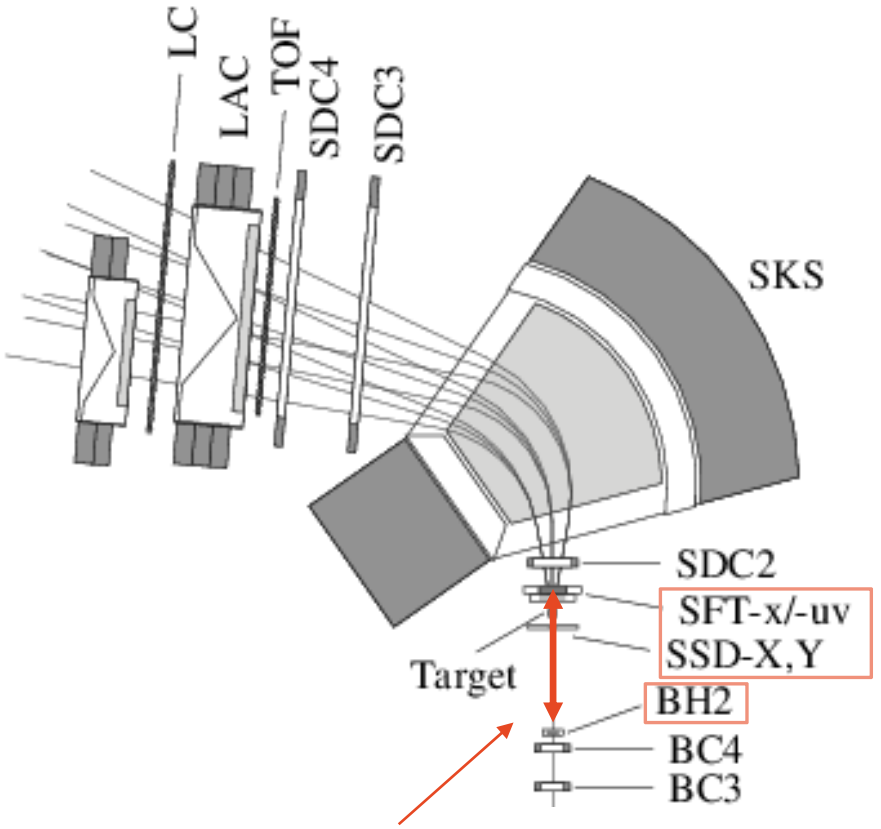
Reduce BG events using fiber tracker

Timing difference between
BH2 and SFT



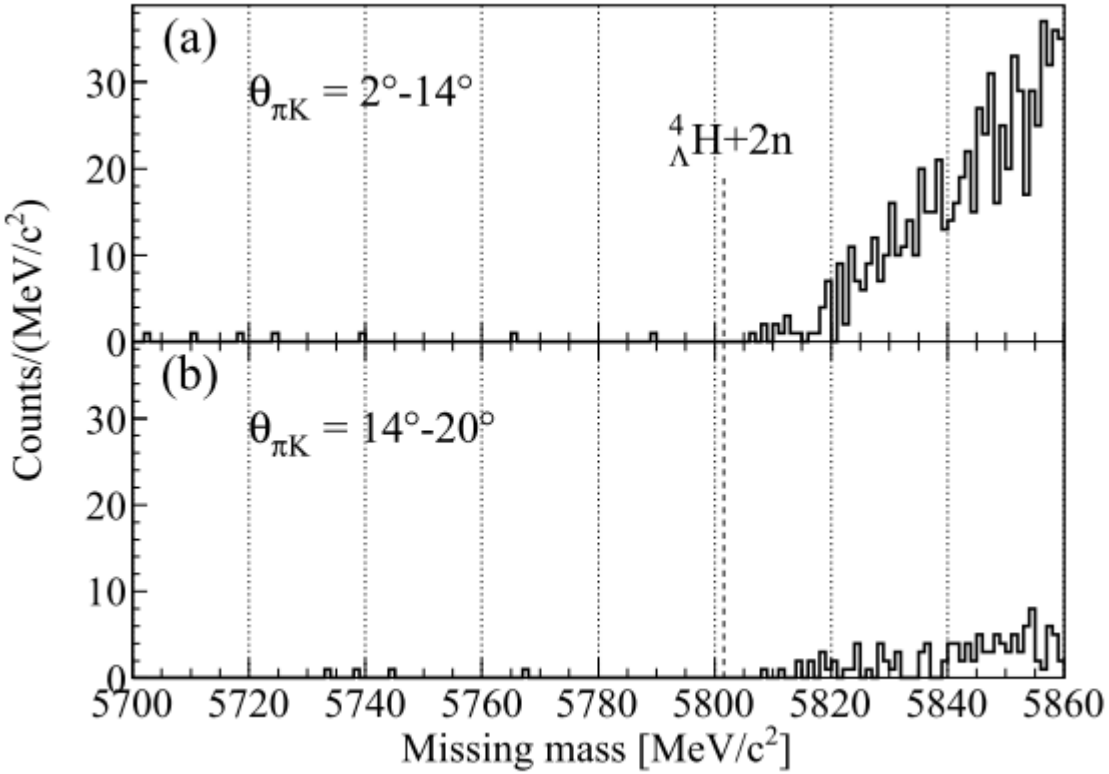
Since this is almost beam TOF between BH2 and SFT, it should make one peak.

2nd peak over 2 ns was made due to the wrong BH2 timing.



Timing information
between the time0 counter and the fiber tracker.

Count base missing-mass spectrum



Back ground level

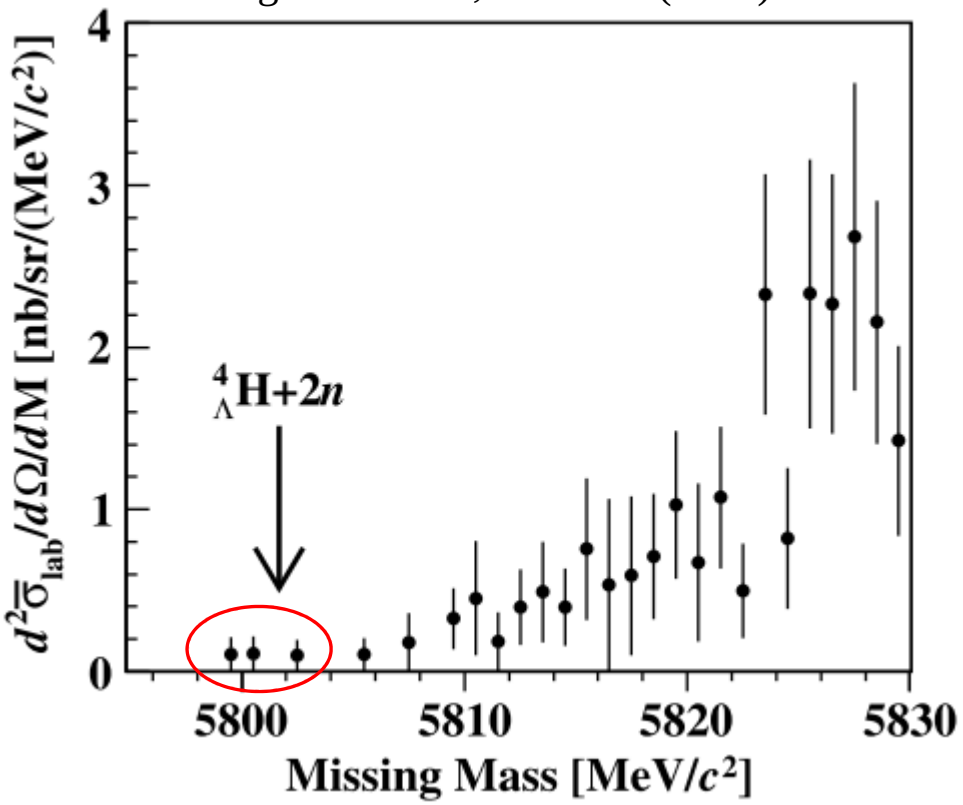
0.39 counts/(MeV/c^2) (PLB result)

↓

0.07 counst/(MeV/c^2) (Present)

Last analysis result

H. Sugimura et al., PLB 729 (2014) 39-44



No peak structure.
Only 3 events around the $^4_\Lambda$H + 2n mass threshold.

Upper limit : 1.2 nb/sr (90% C.L.)

It was not concluded that these events were really whether signal or background.

Improvements in the latest analysis.

- Missing mass resolution
  - To set the narrower integral region if events are remained.
- Back ground level
  - To confirm these events are signal or background.