Study of Λ hypernuclei close to neutron drip-line

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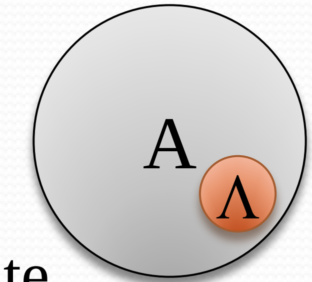
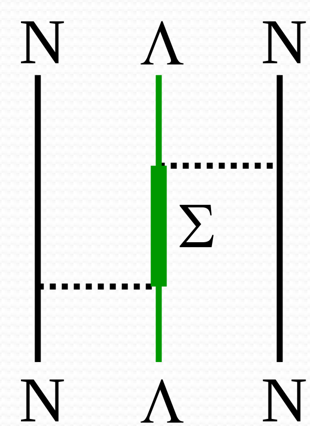
for the **J-PARC E10** Collaboration

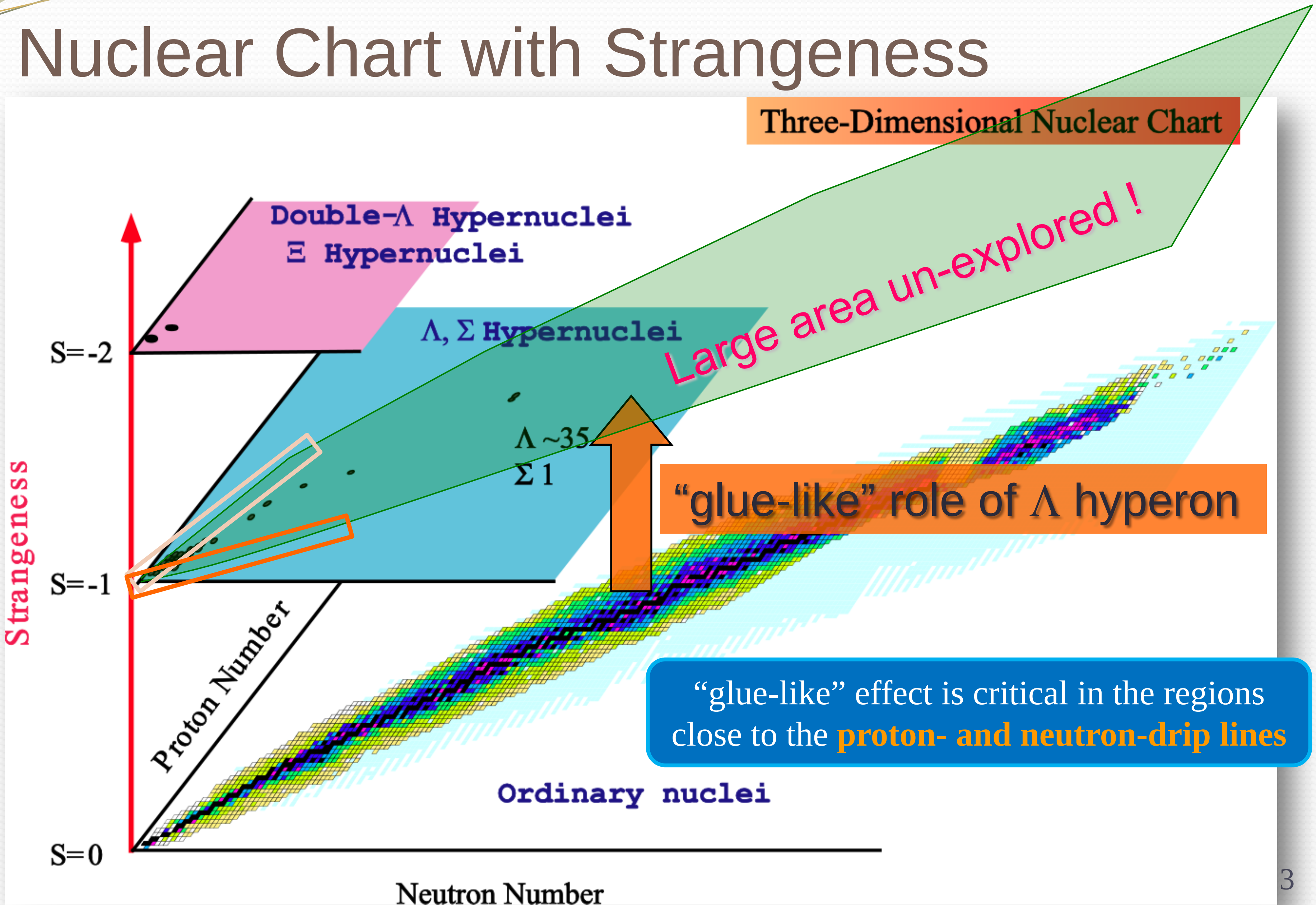
Study of Λ hypernuclei and ΛN interaction



- Λ hypernucleus
  - System made of a Λ hyperon and a nucleus(A)
    - ΛN interaction strong enough to form a bound state
  - Measurement of the binding energies and the nuclear structure provide us the information of ΛN interaction
- How far can we extend the hypernucler chart?
  - Importance of "glue-like role" of Λ hyperon
  - ΛN interaction also stabilize host nucleus
- How about ΛNN 3-body force?
  - Prediction of a strong ΛNN 3-body force
  - Force comes from ΛN-ΣN mixing process



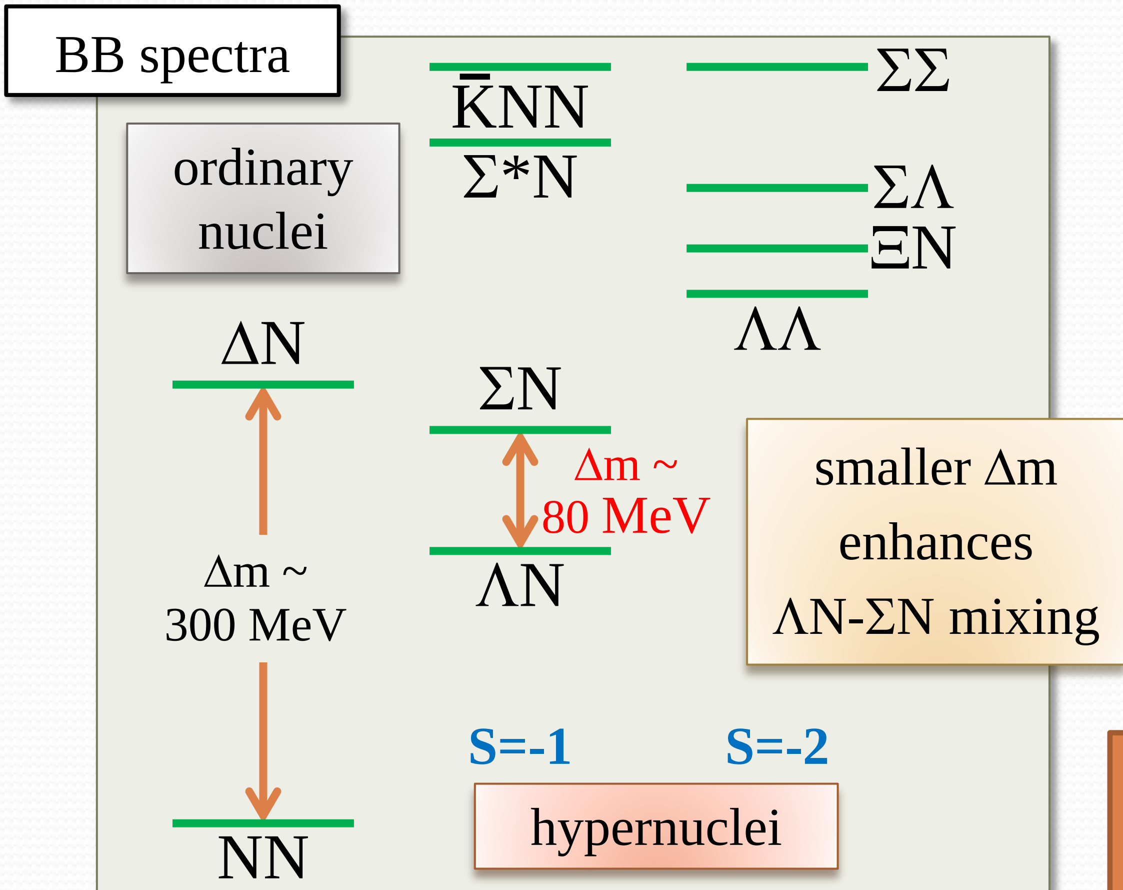
Nuclear Chart with Strangeness



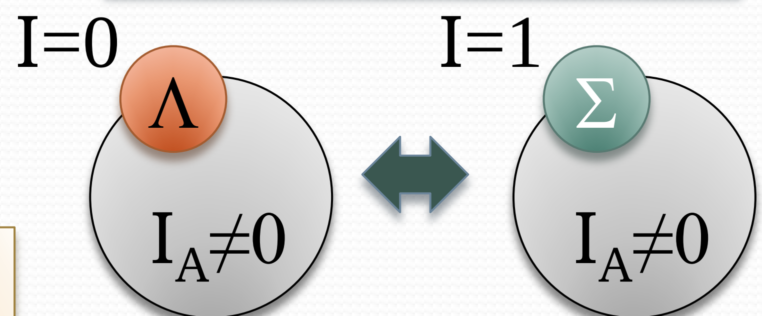
"glue-like" effect is critical in the regions close to the **proton- and neutron-drip lines**

ΛN-ΣN Mixing in Λ Hypernuclei

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



overall conservation of isospin is required

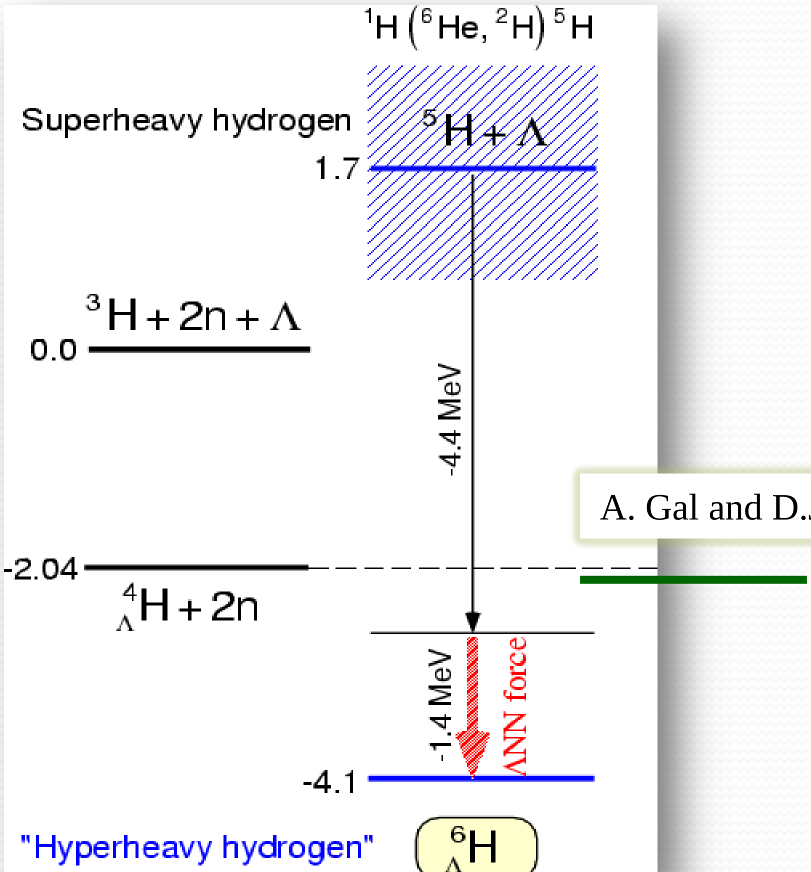


larger mixing expected in nuclei with larger I_A

How large is the mixing in the neutron-rich hypernuclei?

ΛN-ΣN mixing and neutron-rich $^{6}_{\Lambda}$H

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



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

Prediction of Akaishi and Yamazaki

Normal ΛN interaction

B_{Λ} ~ 4.4 MeV

Coherent ΛN-ΣN mixing

B_{Λ} ~ 4.4 + 1.4 MeV

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

Prediction of Gal and Millener

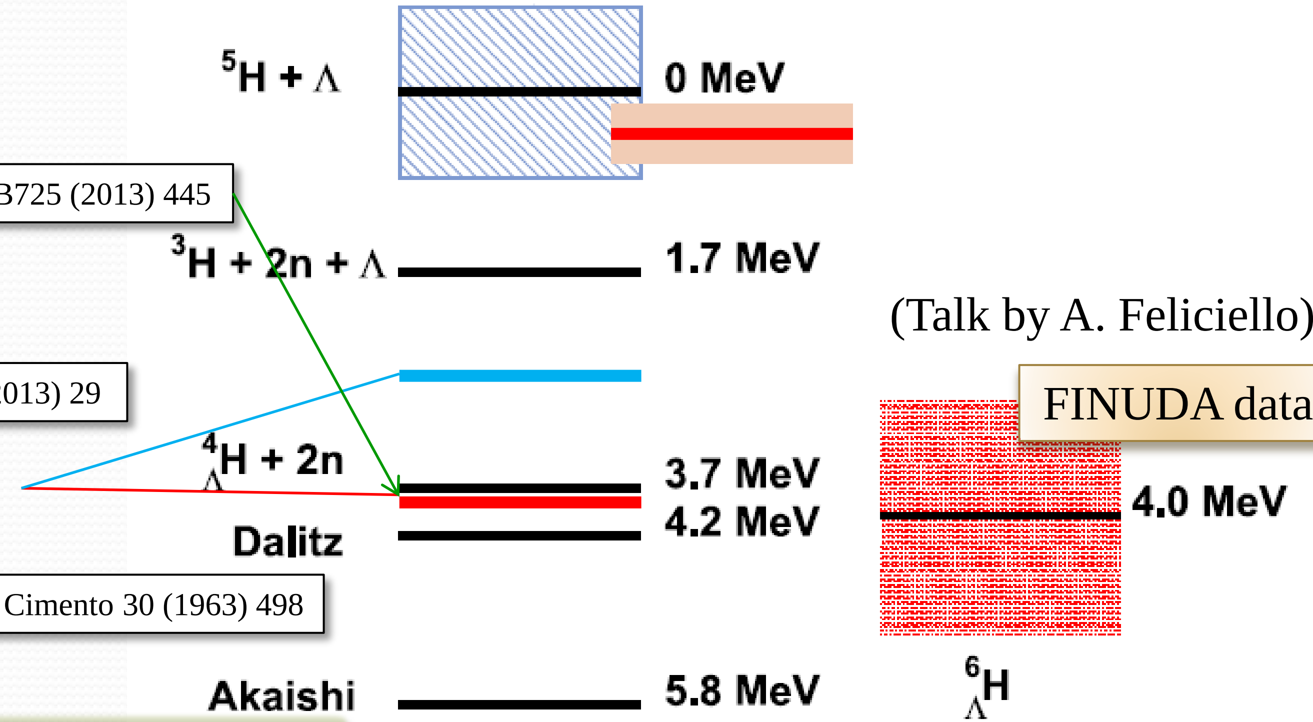
Coherent ΛN-ΣN mixing

$\Delta B_{\Lambda N\text{-}\Sigma N}$ ~ 0.1 MeV

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

${}^{6}_{\Lambda}$H hypernucleus and ΛN interaction

- Recent FINUDA data and theoretical estimations
- 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

More accurate measurement is awaited

Aims of E10 experiment

- E10 proposed study of "neutron-rich Λ hypernuclei"
- **Aim 1**: Λ hypernuclei close to the neutron drip-line
  - Highly neutron-rich Λ hypernuclei
    - $^{6}_{\Lambda}$H (1p, 4n and 1Λ), $^{9}_{\Lambda}$He (2p, 6n and 1Λ)
  - "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

Production of neutron-rich Λ hypernuclei

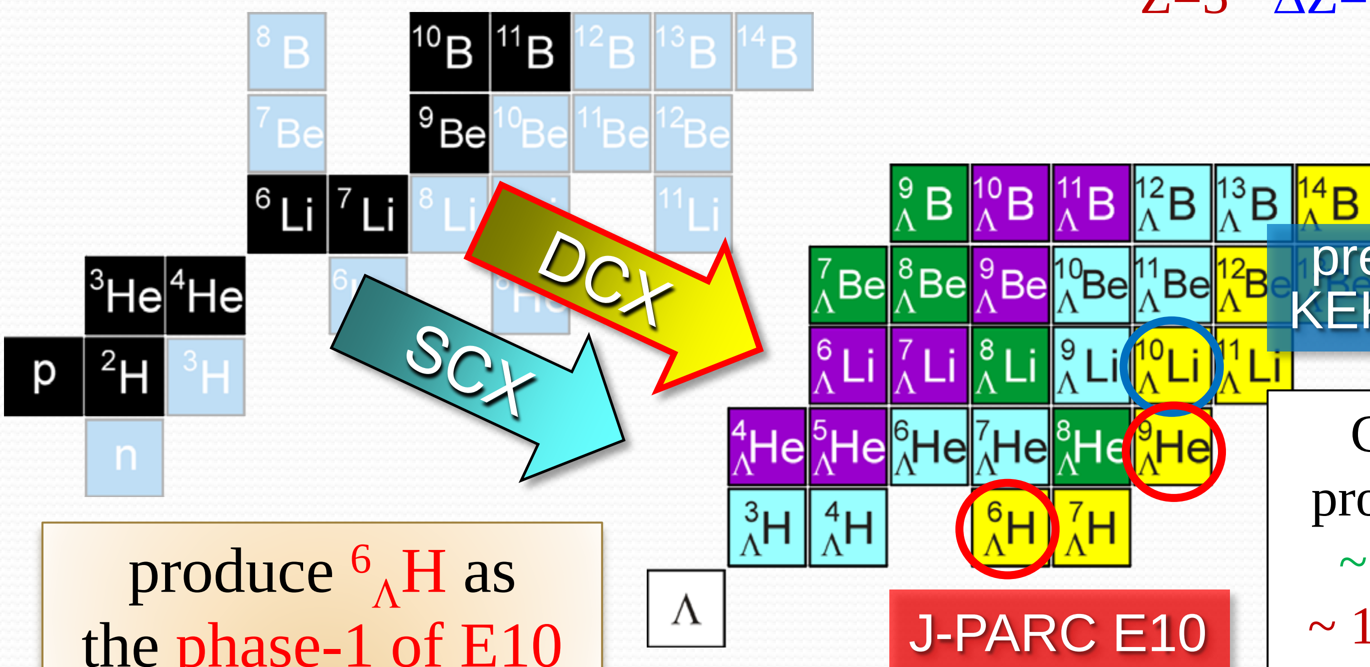
- How to produce?
  - Double Charge-eXchange (DCX) reaction

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

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

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

Z=3 ΔZ=-2 Z=1

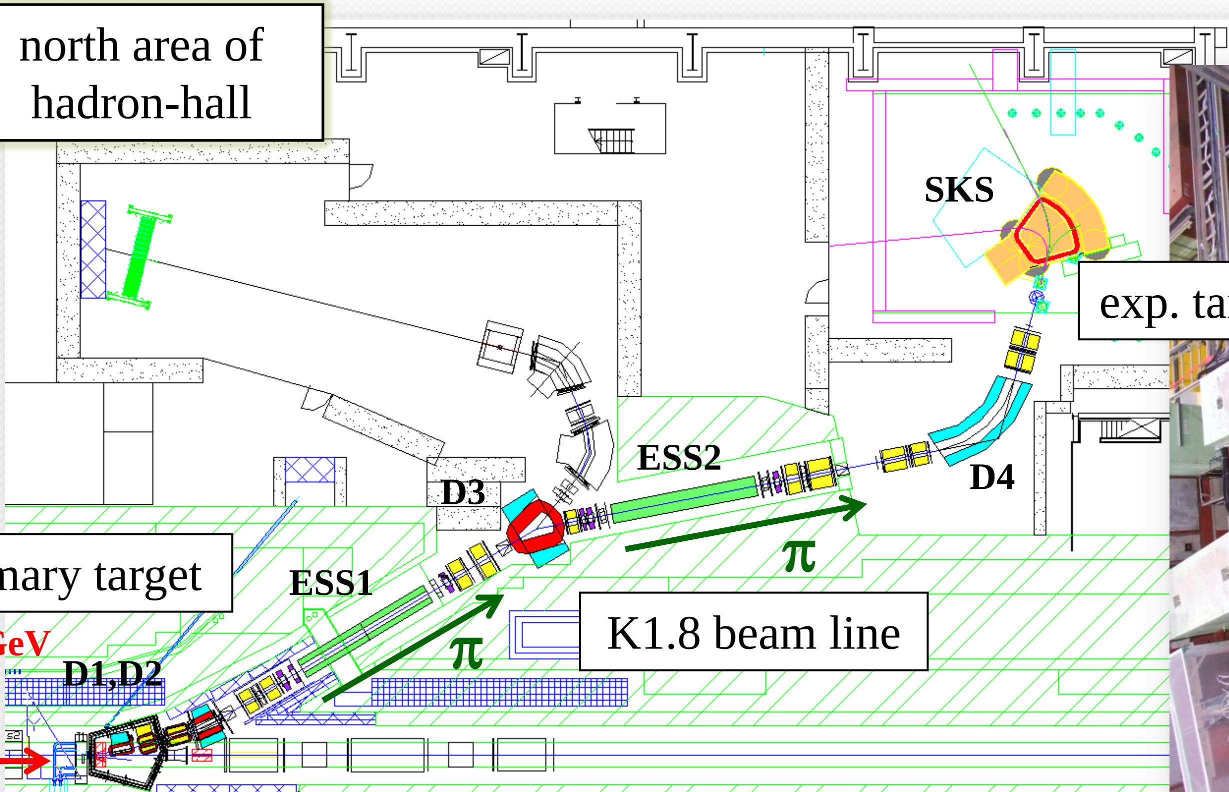


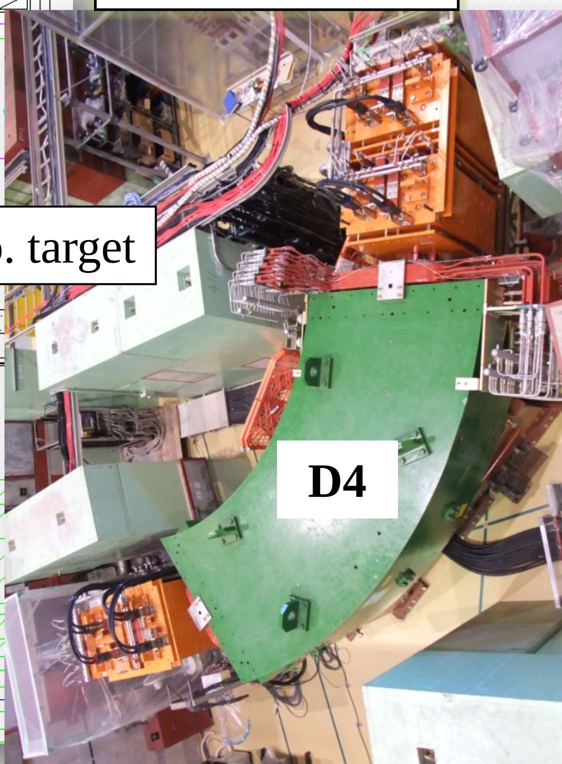
produce $^{6}_{\Lambda}H$ as the phase-1 of E10

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

J-PARC E10 Experiment

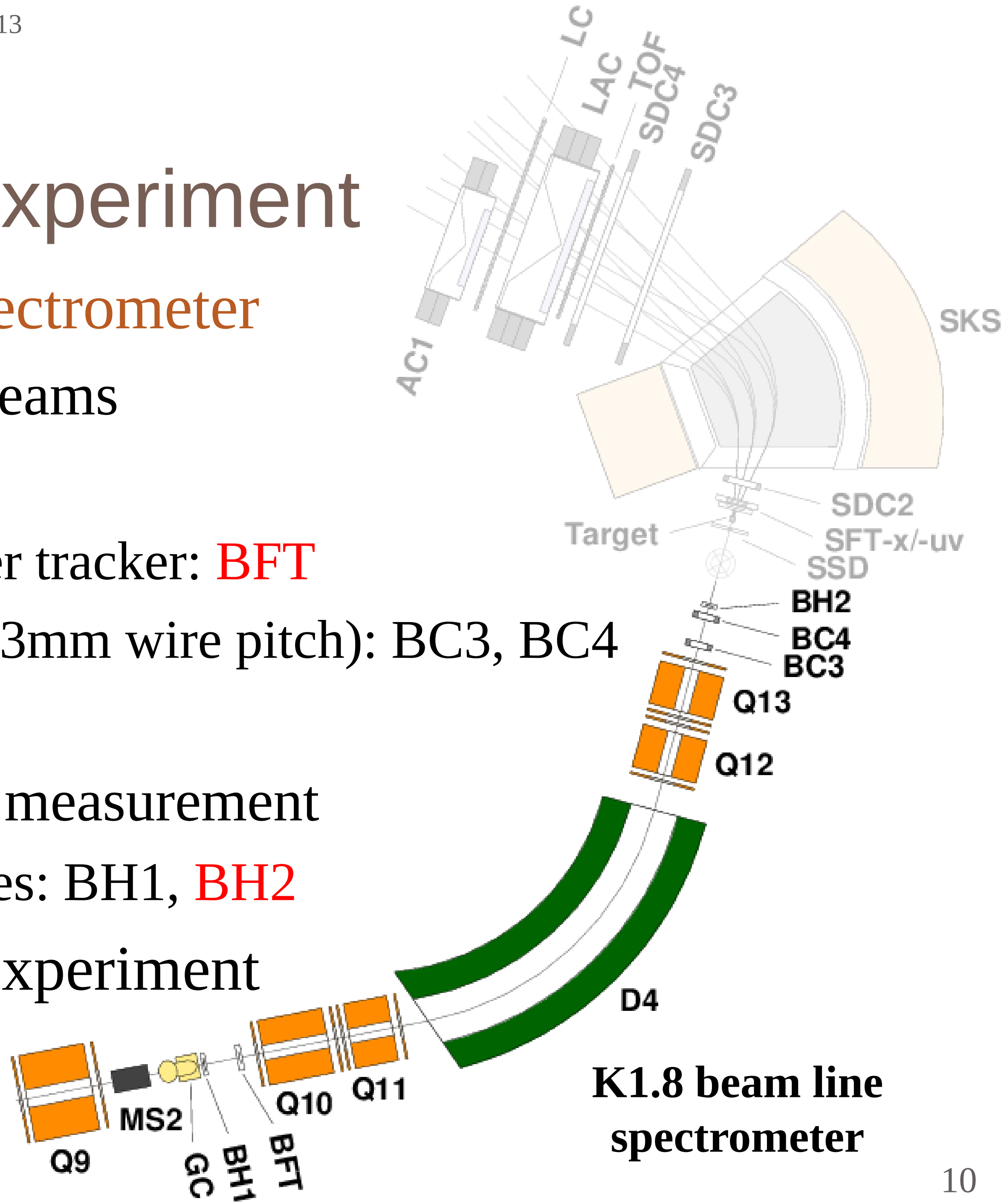
- J-PARC 50GeV Proton-Synchrotron facility
- K1.8 beam line in hadron-hall





Setup of E10 experiment

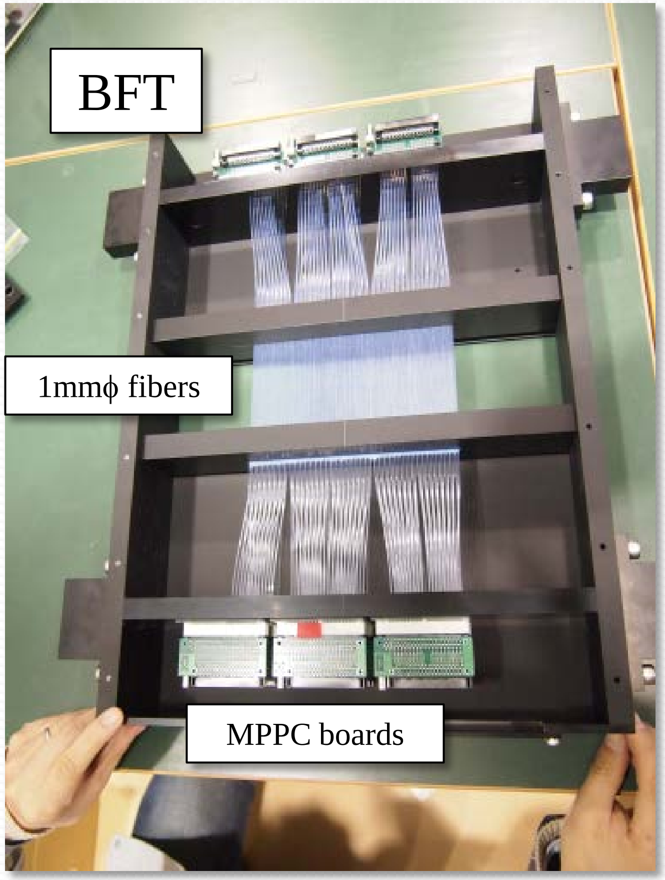
- K1.8 beam line spectrometer
  - 1.2 GeV/c pion beams
  - Beam trackers
    - Scintillating fiber tracker: BFT
    - Drift chambers (3mm wire pitch): BC3, BC4
    - dp/p ~ 3.3×10^{-4}
  - Trigger and TOF measurement
    - Beam hodoscopes: BH1, BH2
- Key issue in E10 experiment
  - High rate beams
    - 10M-12M/spill

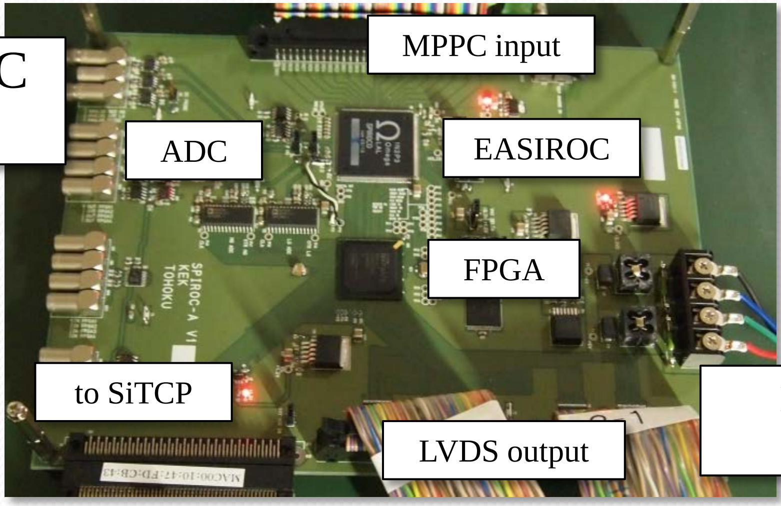


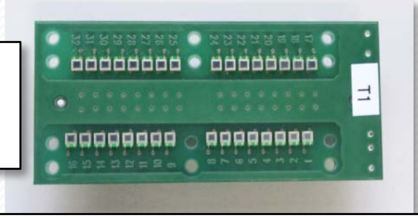
K1.8 beam line spectrometer

BFT (beam fiber tracker)

- 1mm ϕ scintillating fibers
  - x and x' layers staggered by 0.5mm
  - 160 × 2 = 320 fibers
- Read out
  - MPPC+EASIROC
  - Flexible and easy to handle



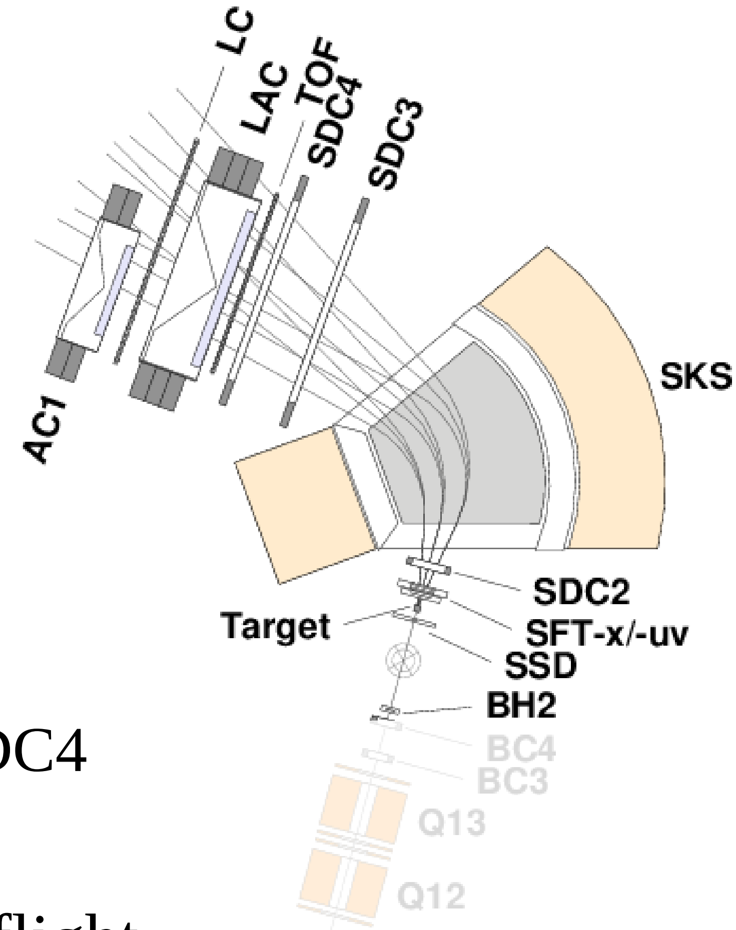




Developed by K. Miwa, S. Hasegawa and R. Honda
(Tohoku Univ. and JAEA)

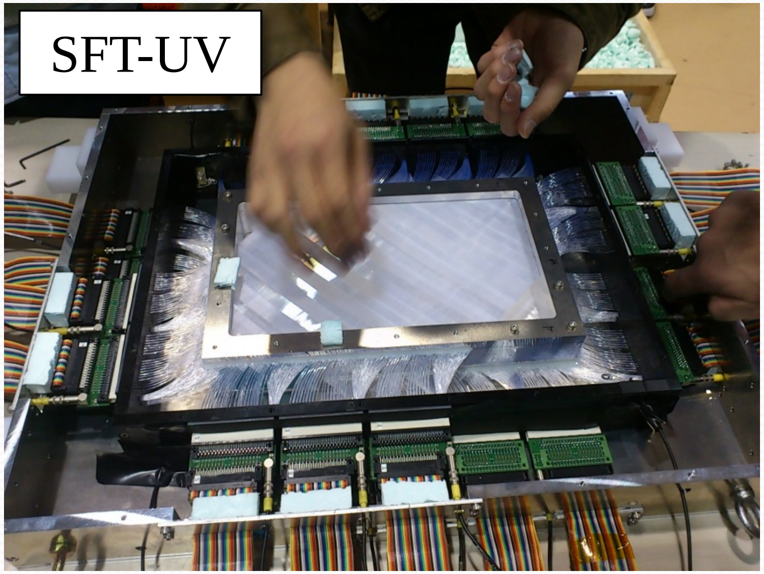
Setup of E10 experiment

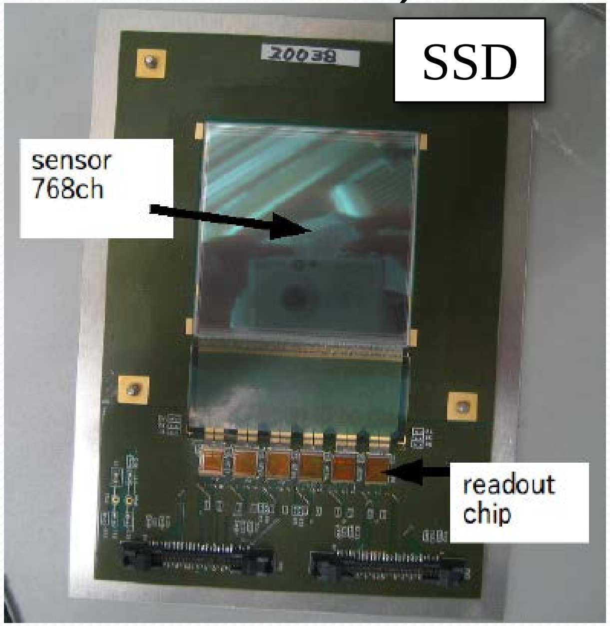
- SKS spectrometer
  - 0.9 GeV/c scattered K^+
  - Tracking of scattered particles
    - Scintillating fiber tracker: SFT
    - Drift chambers: SDC2, SDC3, SDC4
    - $dp/p \sim 10^{-3}$, $d\Omega \sim 100$ msr
  - PID made by BH2-TOF time-of-flight
- Connection of beam π and scattered K^+ tracks
  - SSD was newly installed to improve vertex resolution
- Target (~3.5 g/cm^2)
  - ^{6}Li (95.54% enriched), C and $(CH_2)_n$



SFT and SSD

- SFT (Fiber Tracker for Scattered particle tracking)
  - xx' (ϕ 1mm), u and v (ϕ 0.5mm, $\pm$45 deg. tilt) planes
  - MPPC+EASIROC readout (same as BFT)
- SSD (Silicon Strip Detector)
  - x and y planes (80 μm pitch, single side readout)





E10 proposed run plan and run conditions

- Used high intensity pion beams as proposed
- Production runs were done (55% of proposed)

Proposed values

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

Actual run conditions

Values
1.2 GeV/c
12M/spill
240 hours
1.65T pions
3.5 g/cm^2
10 nb/sr
100 msr
0.5
0.3
90

Sensitivity
~ 0.1 nb/sr

Calibration and diagnostic runs

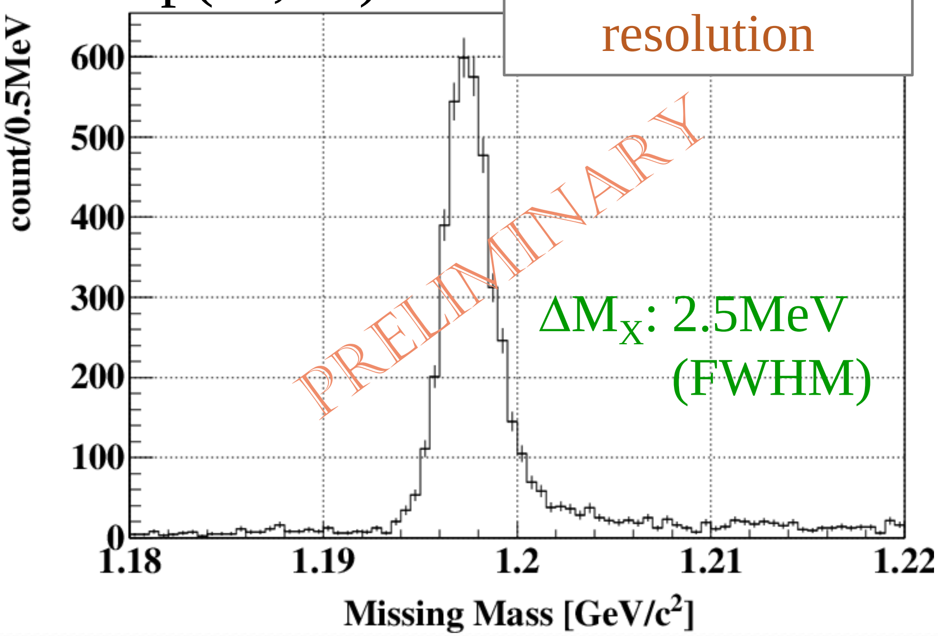
- Momentum calibration of beam and scattered particle
  - Σ^- and Σ^+ production runs (missing-mass calibration)
  - Cross sections are consistent with existing data

5 hours at 10M/spill

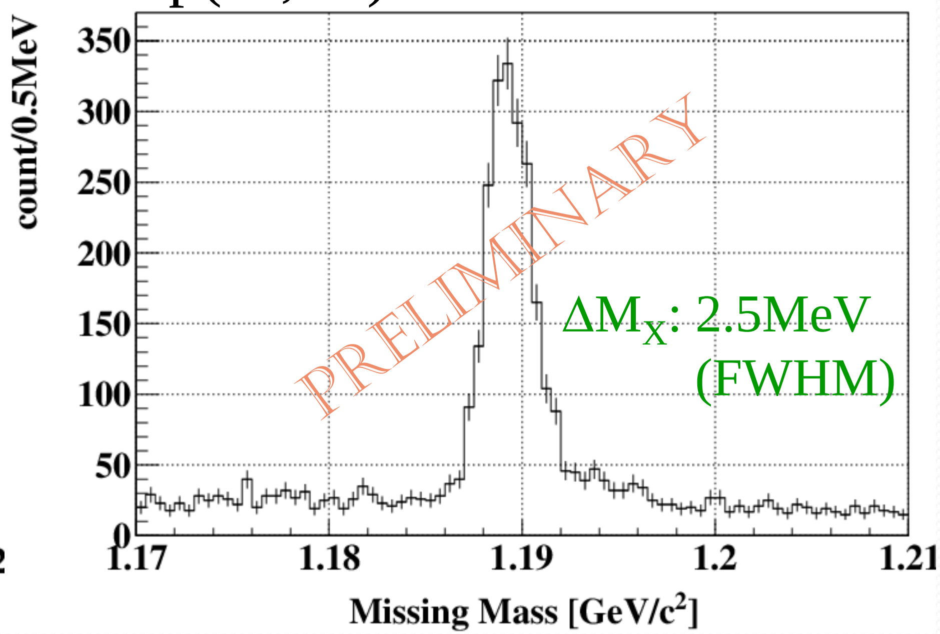
no deterioration of momentum resolution

1 hour at 3M/spill

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



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

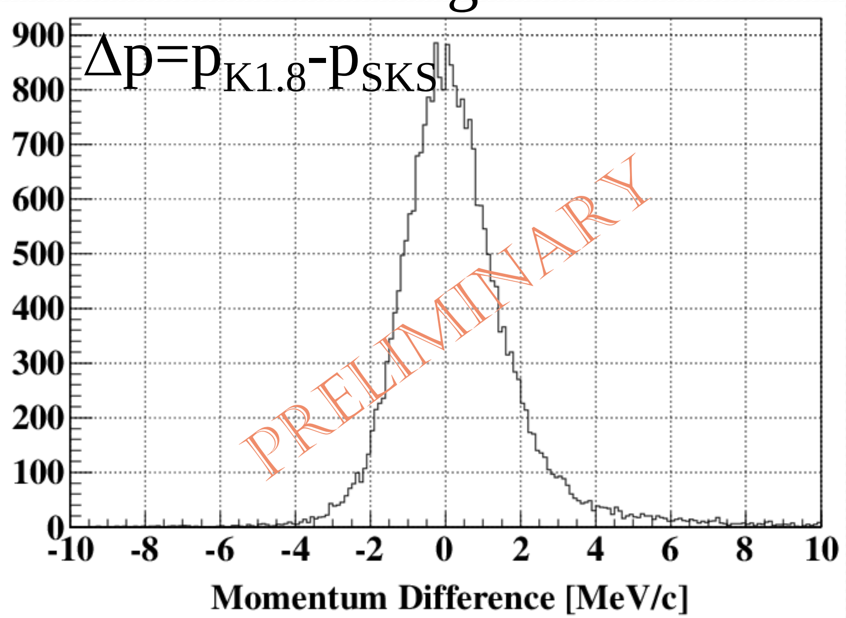


Calibration and diagnostic runs (2)

- Beam through runs (K1.8-SKS mom. mismatch)
- $^{12}{}_{\Lambda}C$ production (check missing-mass resolution)
  - Cross section is consistent with existing data

1 hour (8 settings)

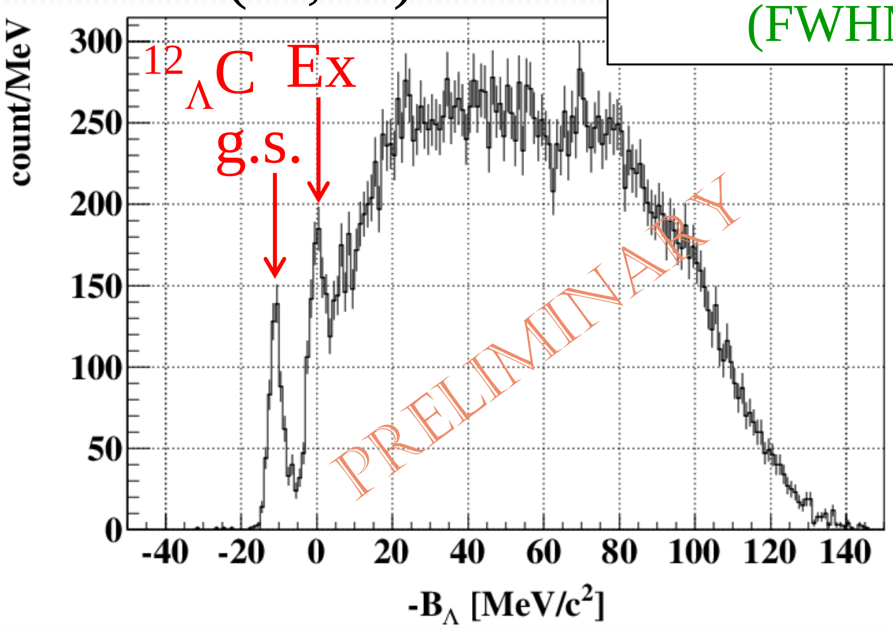
π^+ beam through



13+6 hours at 3M/spill

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

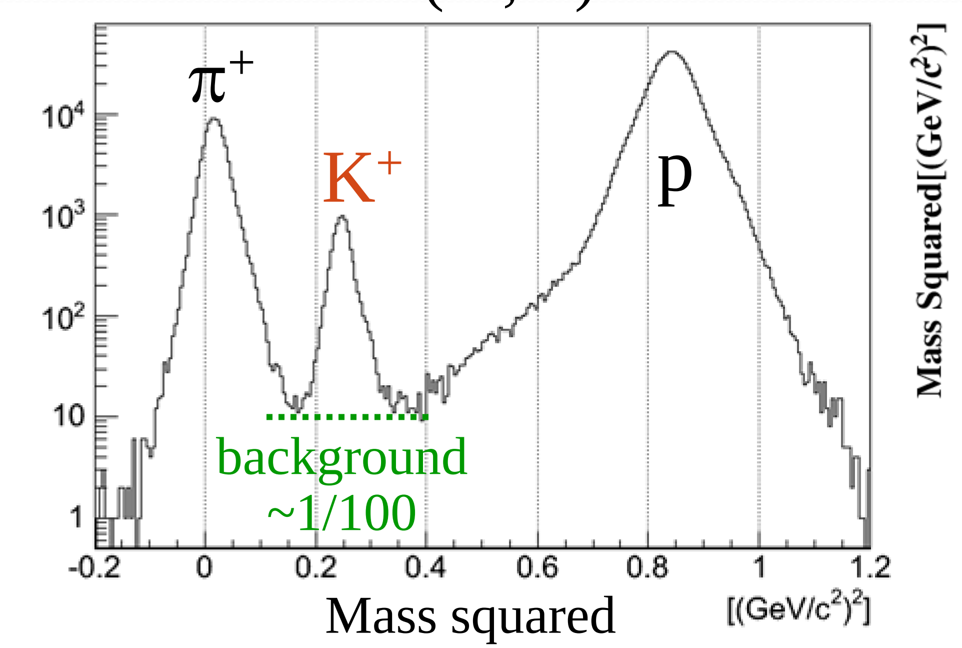
ΔB_Λ: 3.0MeV (FWHM)



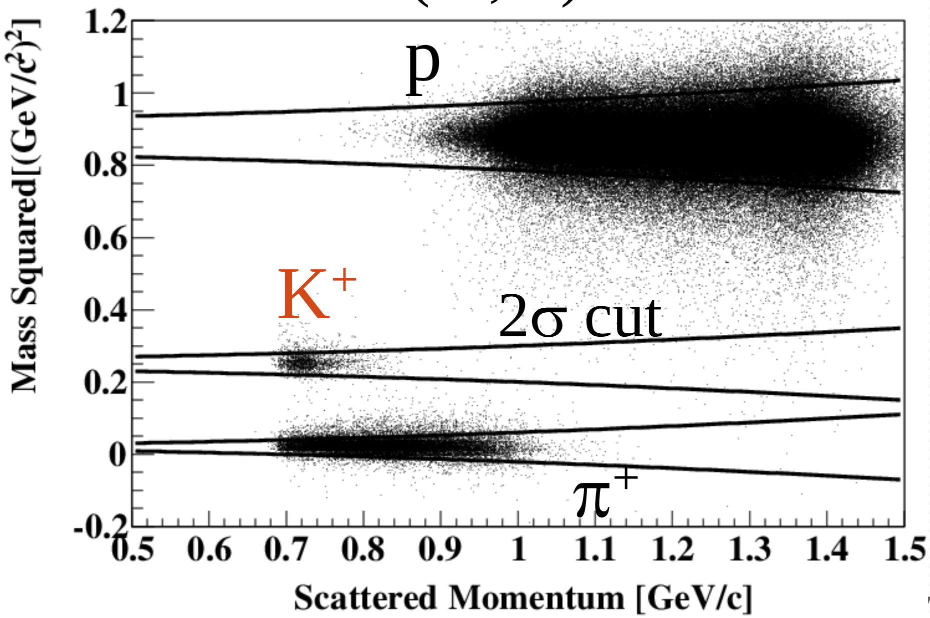
Results of production runs

- PID of scattered K^+ is very important
  - No physical background. Background from miss-PID.
  - Current background level ~ 1/100
  - Momentum dependent selection of Kaon (2-3σ cuts)

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

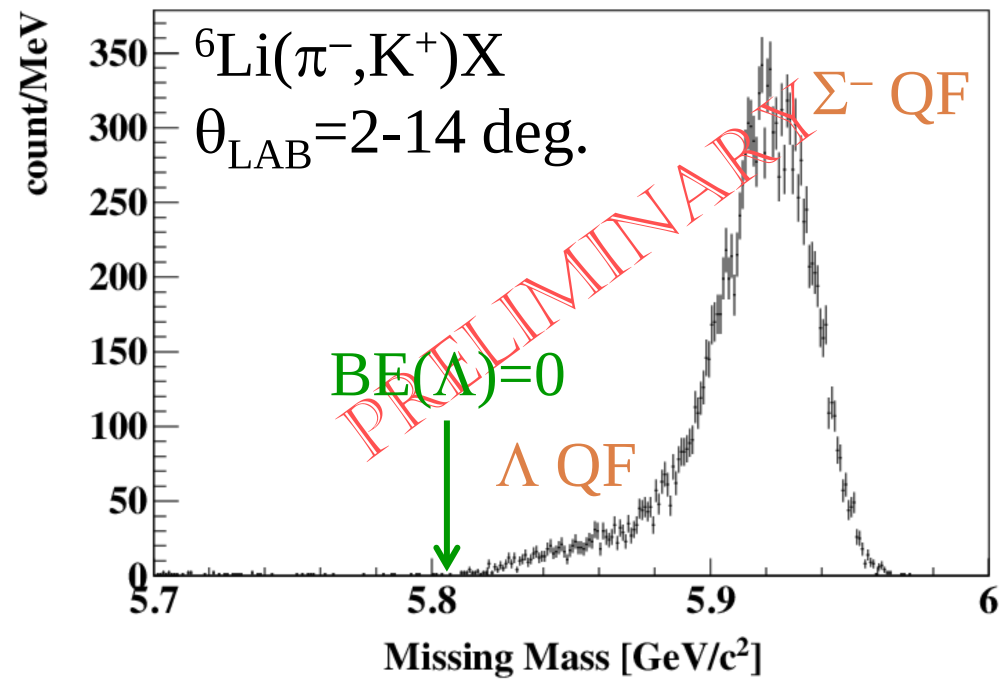


$^6Li(\pi^-,h^+)X$



Results of production runs (2)

- Missing-mass spectrum of the ^{6}Li(π^{-},K^{+})X reaction
  - Current precision of missing-mass is 1 MeV/c^{2} level
  - Tentative angle cut applied 2-14 degrees
    - Same as KEK-E521 and detector acceptance well known



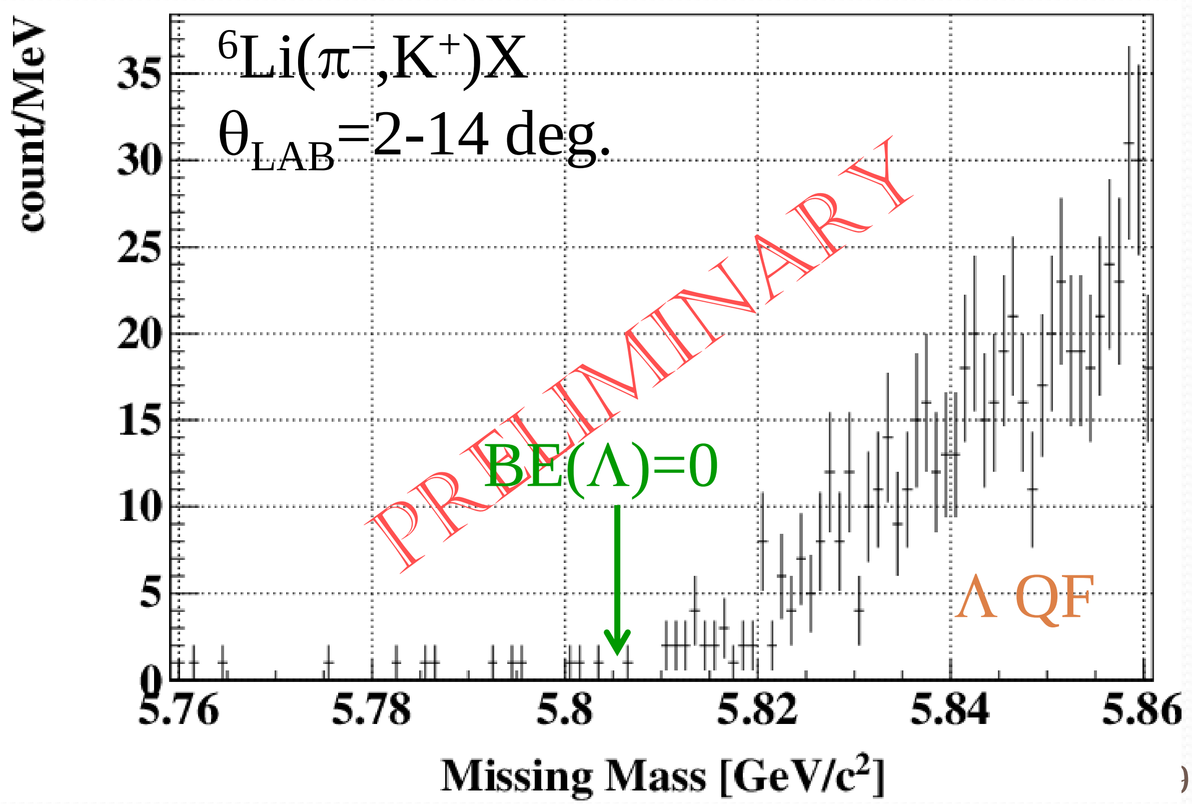
Results of production runs (3)

- No significant peak structure in the threshold region
  - Cross section smaller (< 1 nb/sr) than assumed (10 nb/sr)
- $^{6}_{\Lambda}$H structure and reaction mechanism are not that simple

Background level
0.1-0.3 event/(MeV/c^2)

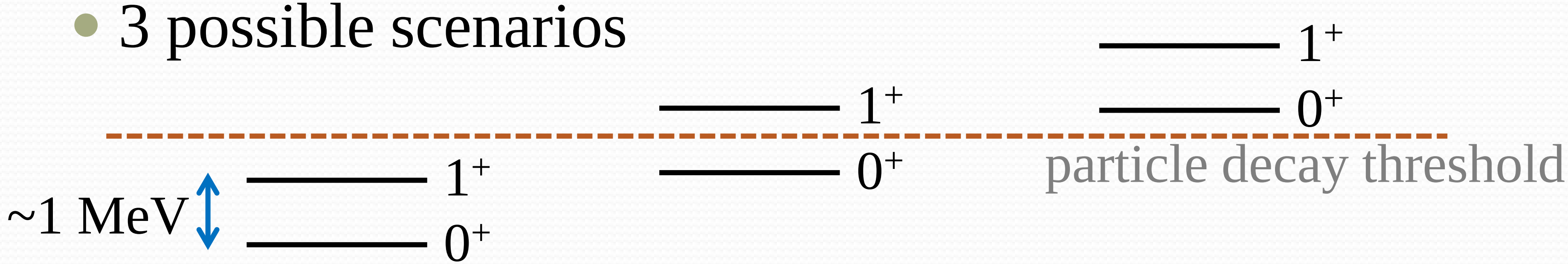
Missing-mass resolution
3.0 MeV/c^2

0.3-0.9 event/state
1 event ~ 0.1nb/sr



Discussion on structure of $^{6}_{\Lambda}\mathrm{H}$

- Possible low-lying states are $^{6}_{\Lambda}\mathrm{H}_{g.s.}(0^+)$ and $^{6}_{\Lambda}\mathrm{H}(1^+)$
- $^{6}\mathrm{Li}(1^+) \rightarrow {}^{6}_{\Lambda}\mathrm{H}_{g.s.}(0^+)$ needs spin-flip amp. but small
- 3 possible scenarios

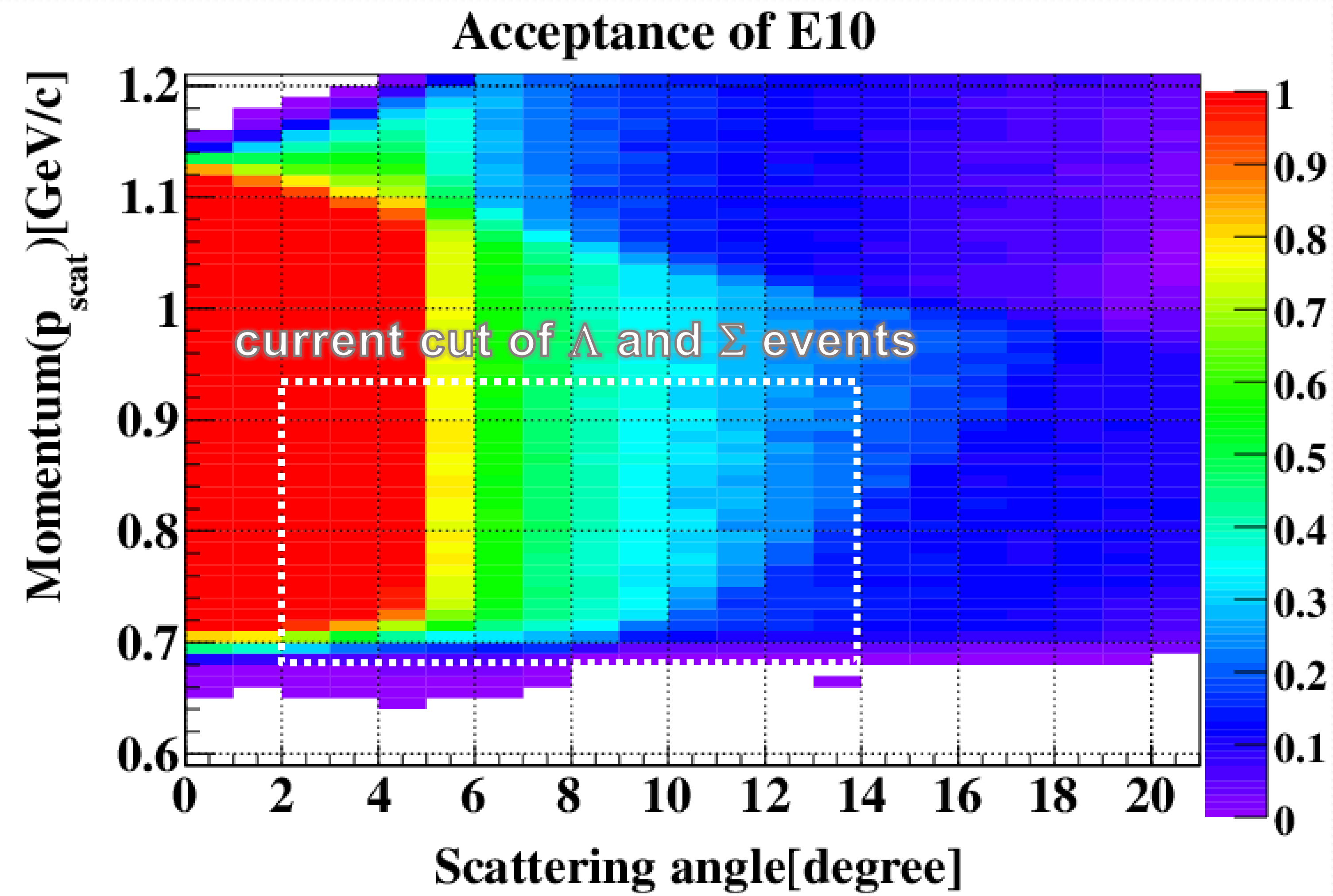


Scenario-1	Scenario-2	Scenario-3
(FINUDA Exp.)	(FINUDA Exp.?)	
observe 1^+	small but possible observation of 0^+	cross sections are vanishing

- Trying to improve sensitivity to see small yield
- Need theoretical input of production cross sections

SKS acceptance map in E10

- Acceptance map and current analysis cut



Summary

- Phase-1 beamtime J-PARC E10
  - Done in December 2012 and January 2013
  - Run at high beam intensity as proposed: 10M-12M/spill
  - 1.65 T pion beams on target (55% of proposal)
- All calibration runs were done ($\Sigma^{\pm}$ and ${}^{12}_{\Lambda}C$)
  - Current precision of missing-mass scale is ~1 MeV/c^2
  - Missing-mass resolution is 3.0 MeV/c^2 (FWHM)
- Analyses of ${}^{6}_{\Lambda}H$ production data are in progress
  - Production cross section (θ_{LAB}=2-14 deg.) < 1 nb/sr
  - Discussed possible scenarios
  - Studies are in progress to improve the sensitivity