# 中性子過剰ハイパー核の研究（J-PARC E10 実験）

計画研究A02：中性子過剰核物質中のストレンジネス

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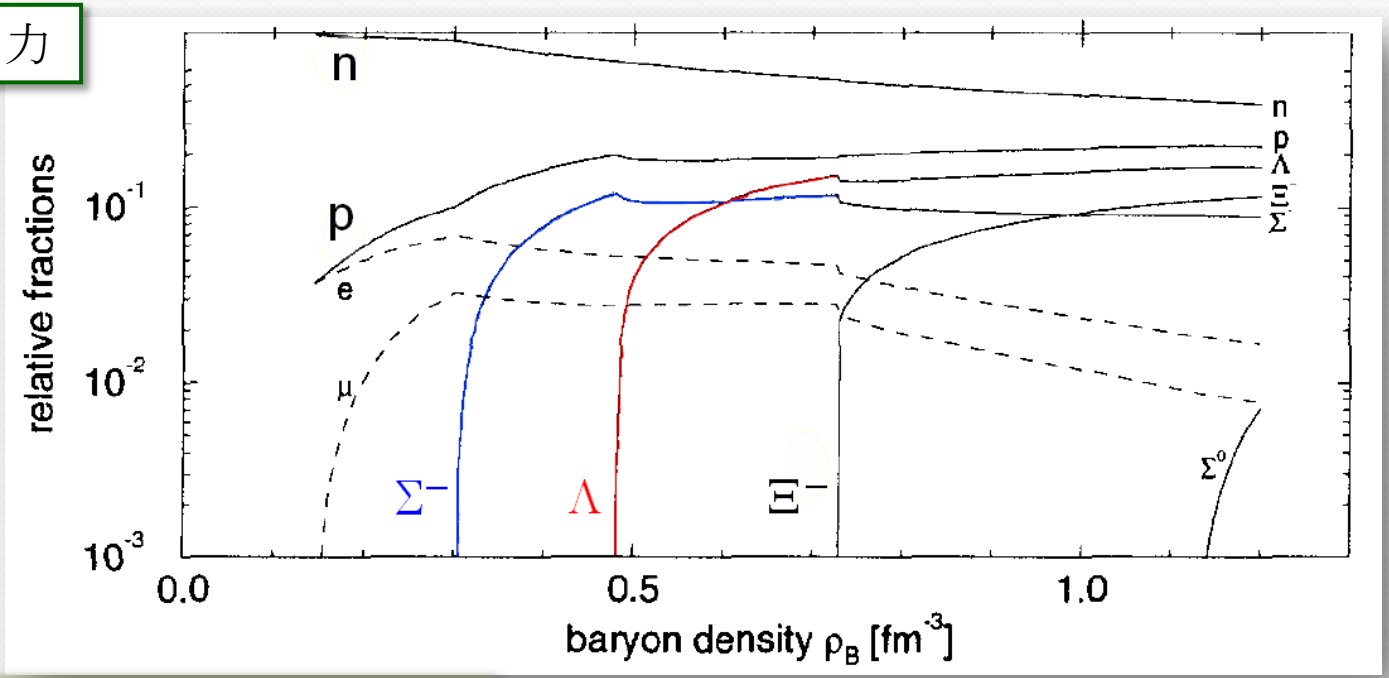
ハドロン実験施設 J-PARC

# YN 相互作用と中性子星

- neutron, proton, electron, muon and more
  - Fermi energy in neutron star core is considerably high
  - Exotics: hyperons, mesons, quarks, …
  - Effect of YN interaction

ΣN: 引力




S. Balberg and A. Gal NP A625 (1997) 435

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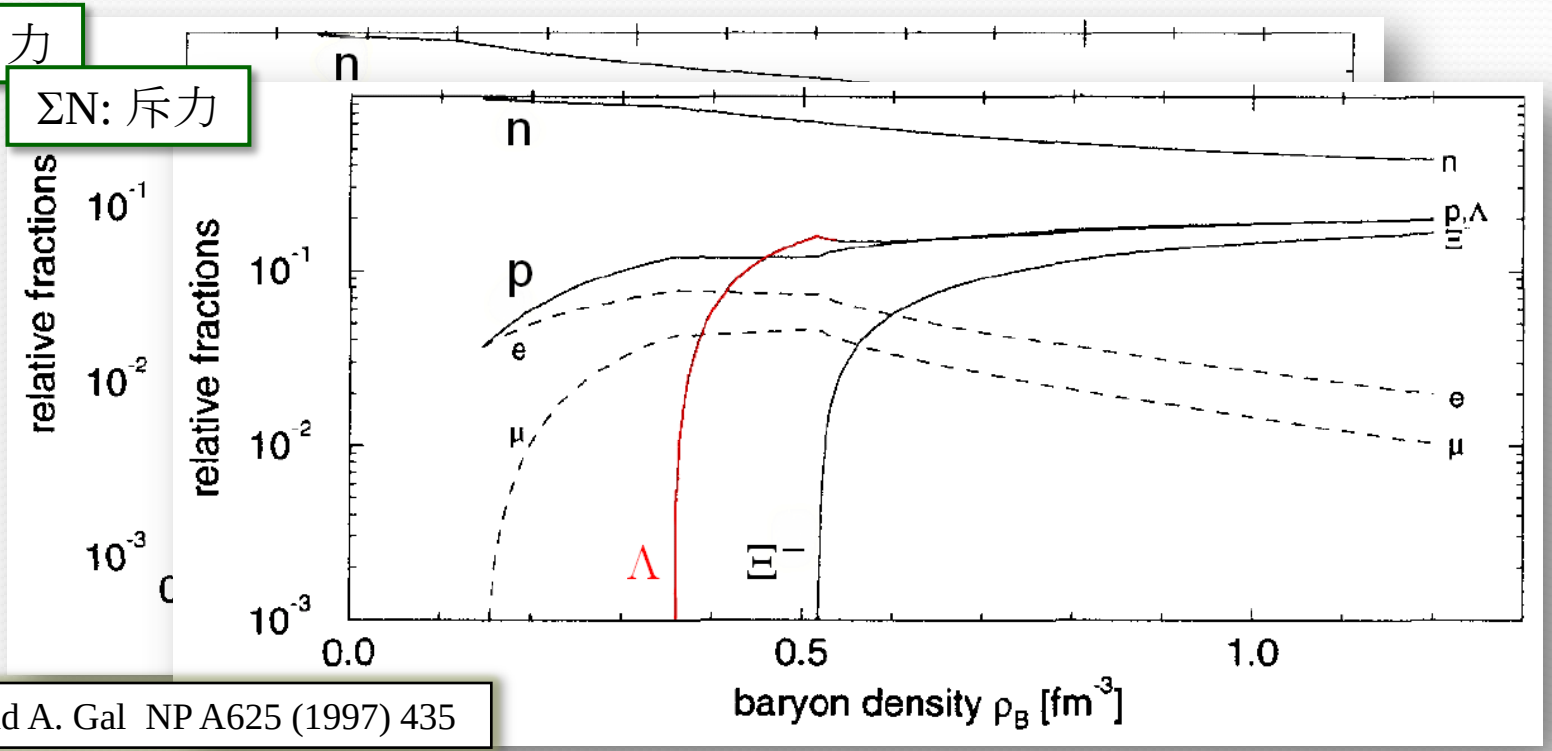


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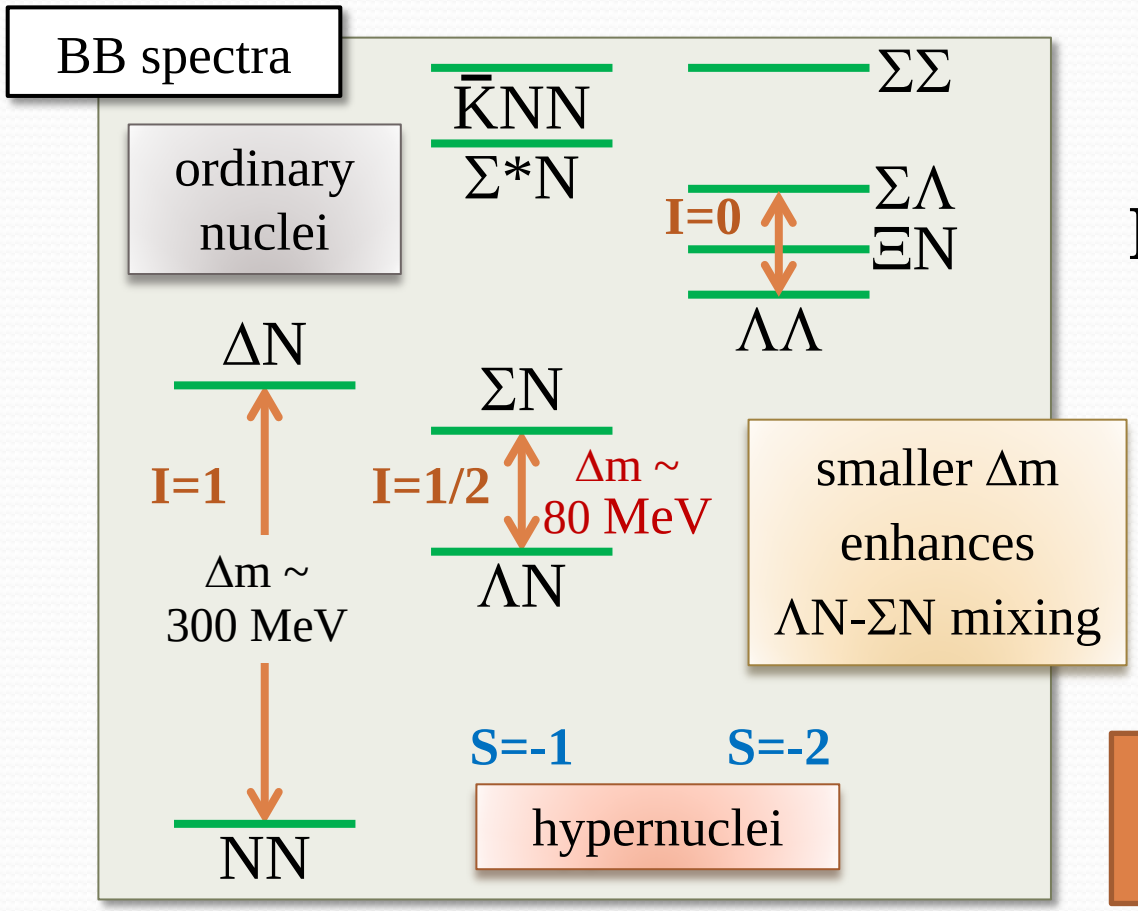
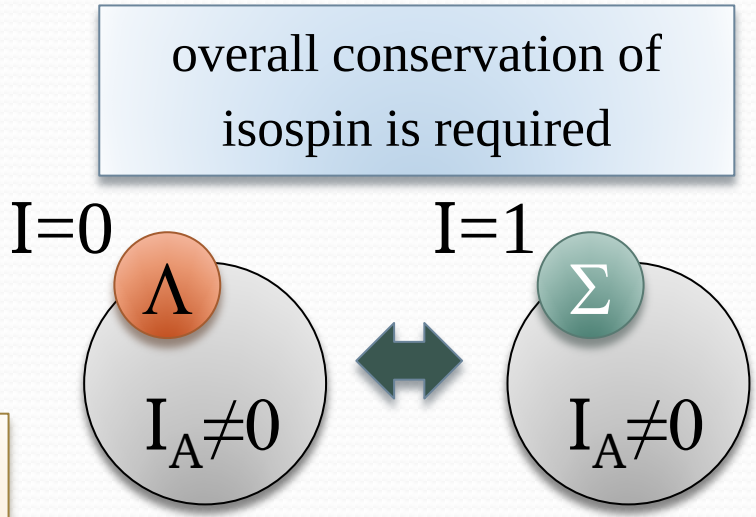
# YN 相互作用の理解

- ΛN interaction (S=-1)
  - Attractive → Λ and ΛΛ hypernuclei, glue-like role of Λ
- ΣN interaction (S=-1)
  - $^{4}_{\Sigma}$He hypernucleus: strong isospin dependence
  - Repulsive? (KEK E438), ΣN scattering (A02 by Miwa)
- ΞN interaction (S=-2)
  - A01 by Takahashi and J-PARC E05 by Nagae
- ΛN-ΣN mixing (ΞN-ΛΛ mixing)
  - Coherent ΛN-ΣN mixing (one of ΛNN 3-body forces)
- 3-body (or many-body) force
  - Universal 3-body force?: short-range and repulsive

# ΛN-ΣN Mixing in Λ Hypernuclei

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



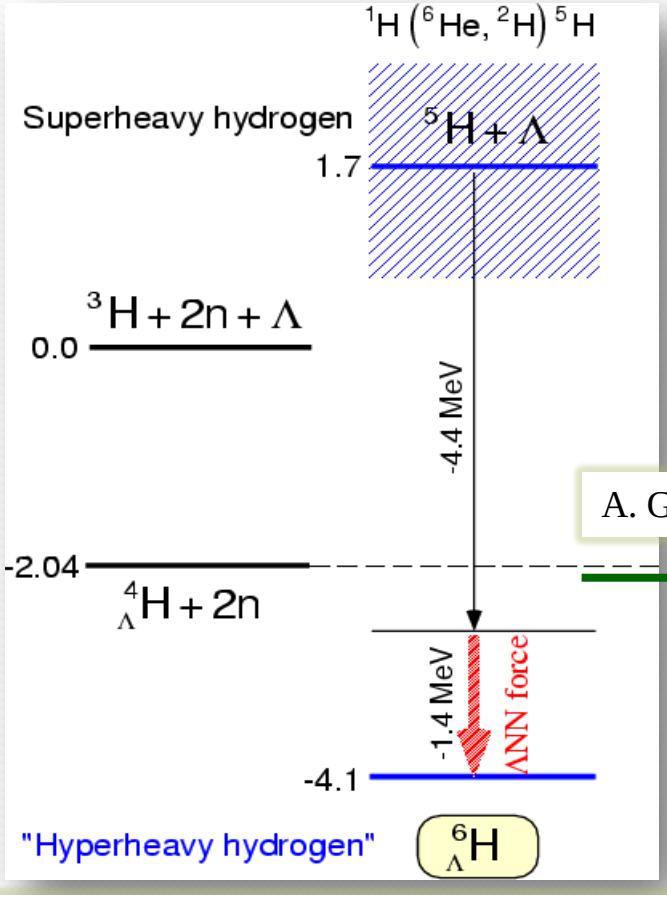




larger mixing expected in nuclei with larger $I_A$

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 (glue-like role)
$B_{\Lambda}$ ~ 4.4 MeV

Coherent ΛN-ΣN mixing
$B_{\Lambda}$ ~ 4.4 + 1.4 MeV

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

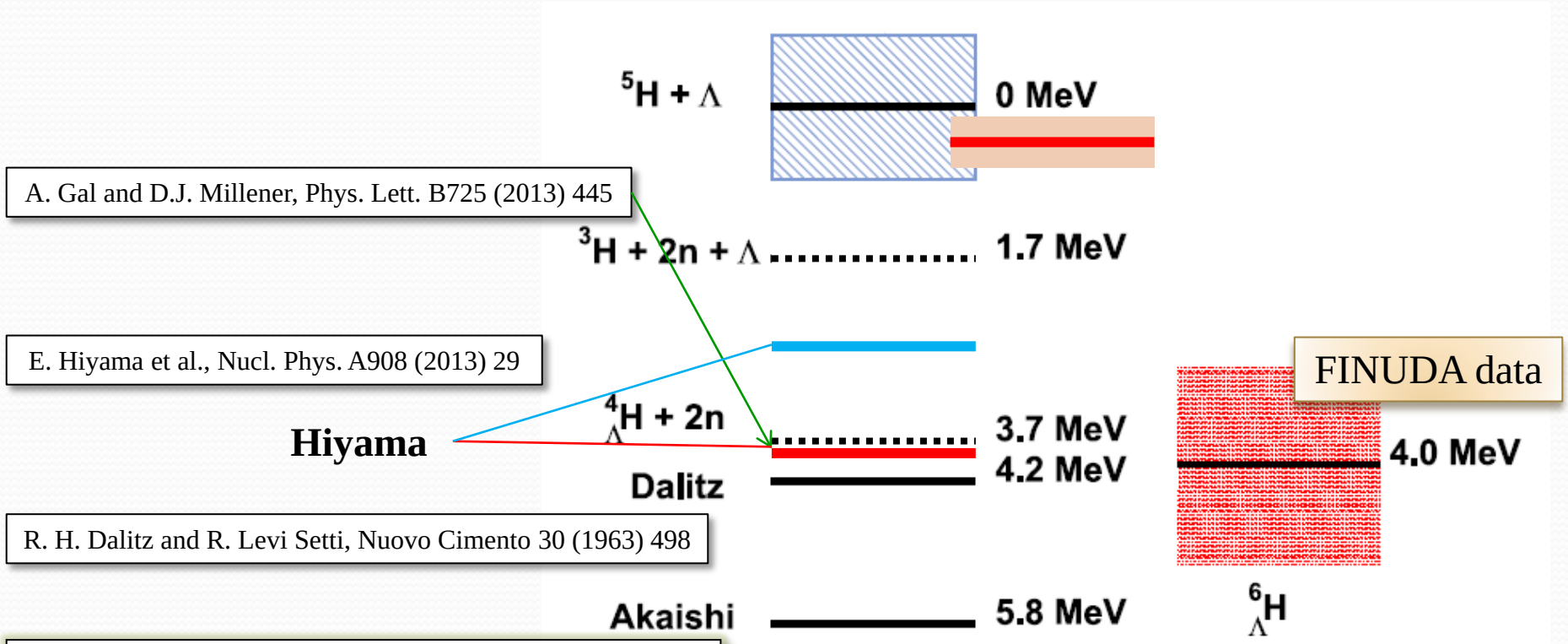
Prediction of Gal and Millener

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

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

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

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




H. Sugimura et al., J-PARC E10 collaboration, arXiv:1310.6104

# J-PARC E10 実験の概要

- **目的**: 中性子過剰 Λ ハイパー核の生成
- **Aim 1**: 中性子ドリップ・ライン近傍のハイパー核生成
  - 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**: 中性子過剰環境での ΛN 相互作用
  - 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

# 中性子過剰 Λ ハイパー核の生成法

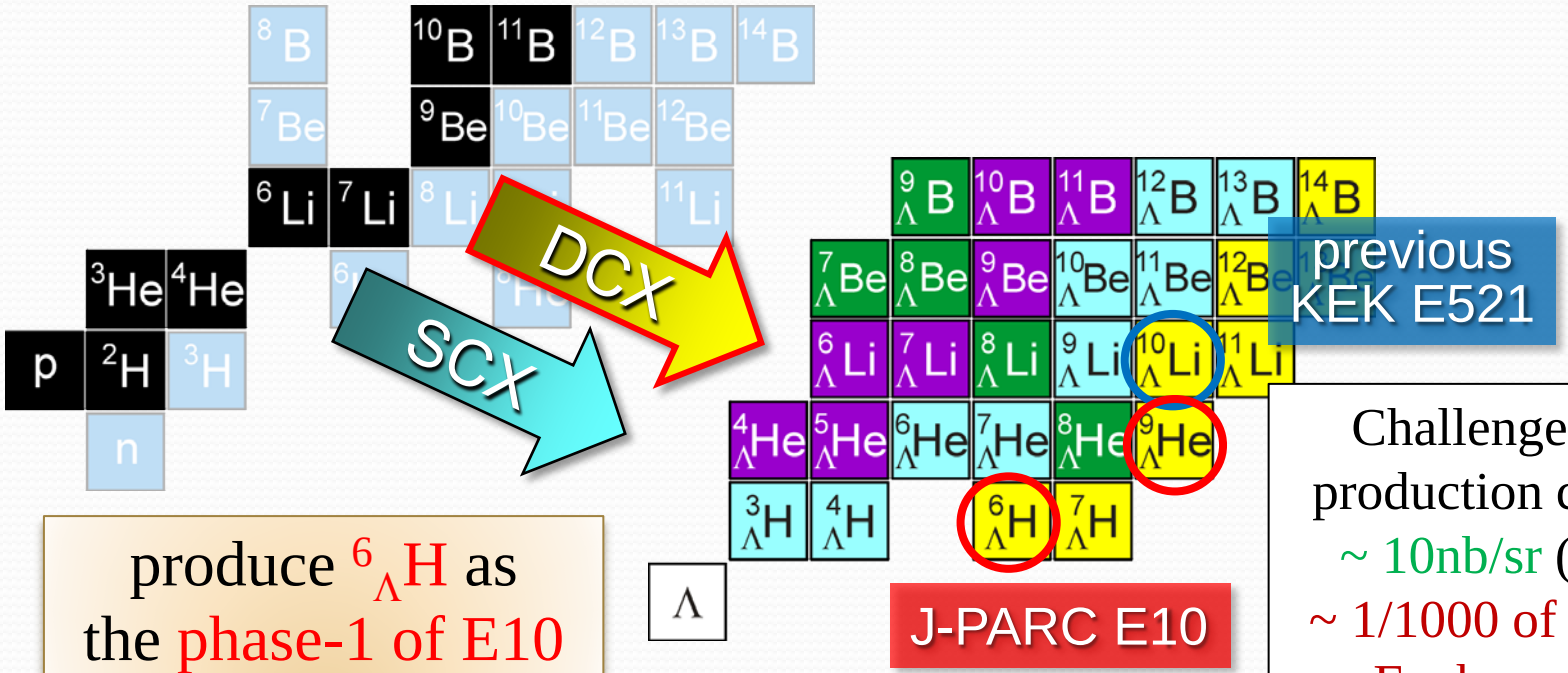
- How to produce?
  - Double Charge-eXchange (DCX) reaction

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



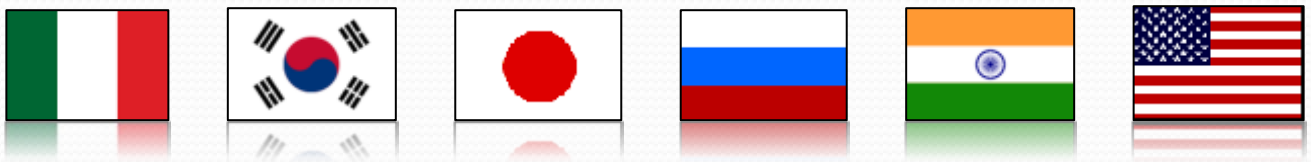

produce $^{6}_{\Lambda}H$ as the phase-1 of E10

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

# J-PARC E10 collaboration

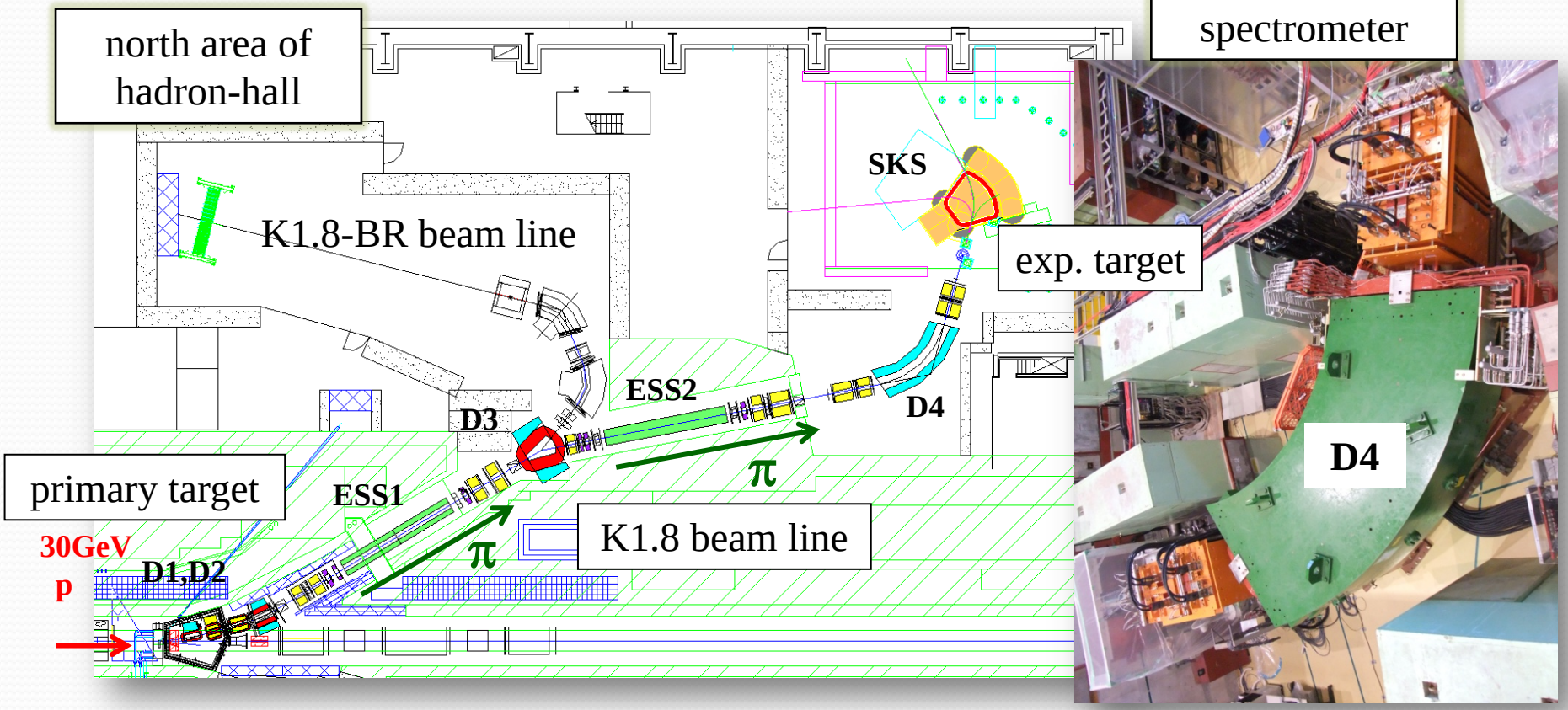
M. Agnello, J.K. Ahn, S. Ajimura, Y. Akazawa, N. Amano, K. Aoki, H.C. Bhang, N. Chiga, M. Endo, P. Evtoukhovitch, A. Feliciello, H. Fujioka, T. Fukuda, S. Hasegawa, S. Hayakawa, R. Honda, K. Hosomi, S.H. Hwang, Y. Ichikawa, Y. Igarashi, K. Imai, N. Ishibashi, R. Iwasaki, C.W. Joo, R. Kiuchi, J.K. Lee, J.Y. Lee, K. Matsuda, Y. Matsumoto, K. Matsuoka, K. Miwa, Y. Mizoi, M. Moritsu, T. Nagae, S. Nagamiya, M. Nakagawa, M. Naruki, H. Noumi, R. Ota, B.J. Roy, P.K. Saha, A. Sakaguchi, H. Sako, C. Samanta, V. Samoilov, Y. Sasaki, S. Sato, M. Sekimoto, Y. Shimizu, T. Shiozaki, K. Shirotori, T. Soyama, H. Sugimura, T. Takahashi, T.N. Takahashi, H. Tamura, K. Tanabe, T. Tanaka, K. Tanida, A.O. Tokiyasu, Z. Tsamalaidze, M. Ukai, T.O. Yamamoto, Y. Yamamoto, S.B. Yang and K. Yoshida

Politecnico di Torino, Pusan National University, RCNP, Tohoku University, KEK, Seoul National University, Osaka University, JINR, INFN, Kyoto University, Osaka Electro-Communication University, JAEA, BARC, Virginia Military Institute, RIKEN



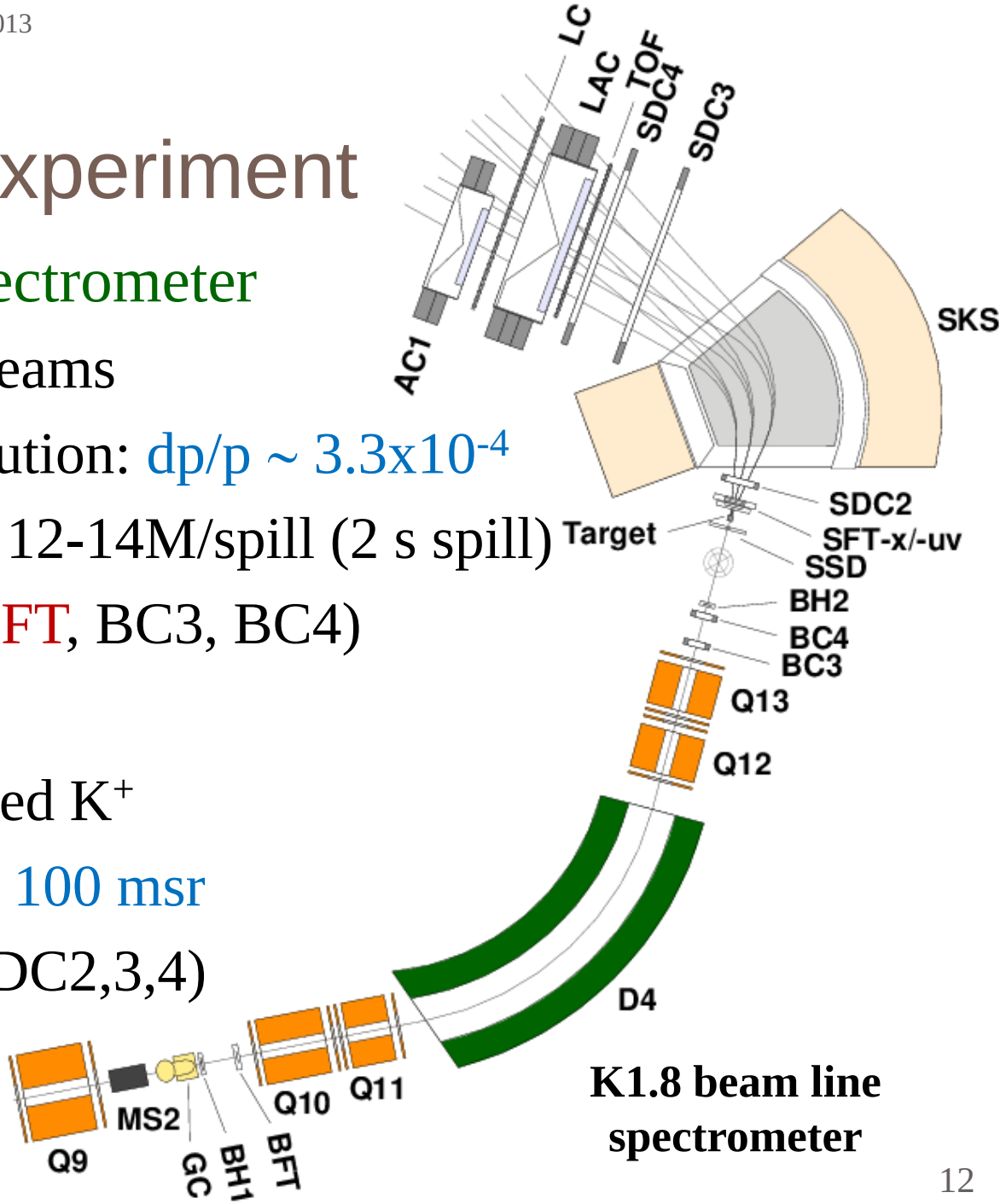
# J-PARC E10 Experiment

- 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
  - Momentum resolution: dp/p ~ $3.3 \times 10^{-4}$
  - High rate beams: 12-14M/spill (2 s spill)
  - Beam trackers (BFT, BC3, BC4)
- SKS spectrometer
  - 0.9 GeV/c scattered $K^+$
  - dp/p ~ $10^{-3}$, dΩ ~ 100 msr
  - Trackers (SFT, SDC2,3,4)
- Target ($^6$Li, C etc.)
- Vertex det. (SSD)



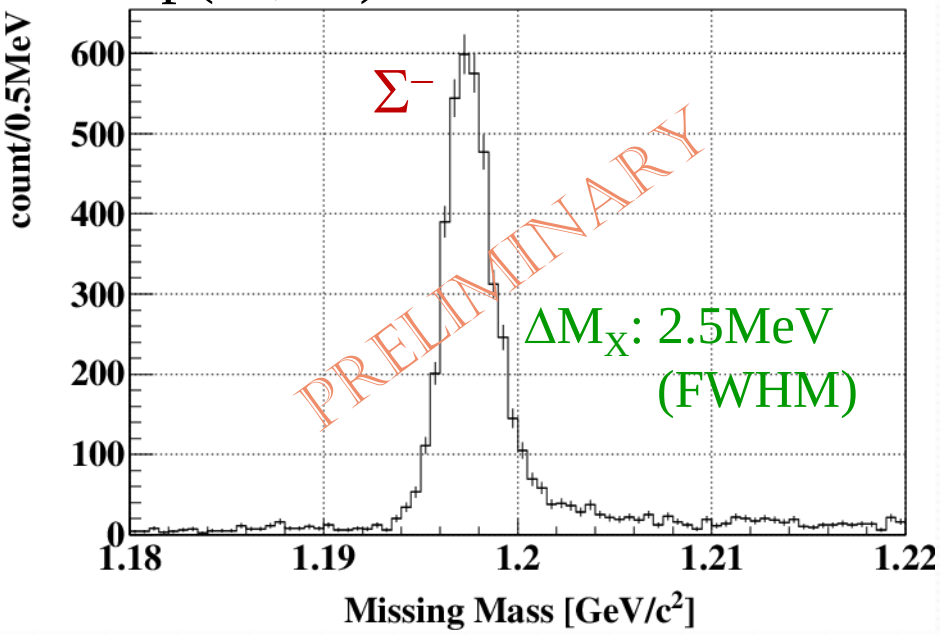

**K1.8 beam line spectrometer**

# Calibration and diagnostic runs

- Momentum calibration of beam and scattered particle
  - $\Sigma^-$ and $\Sigma^+$ production runs, $\pi^-$ beam-through runs
- Estimation of missing-mass resolution by $^{12}_{\Lambda}C$

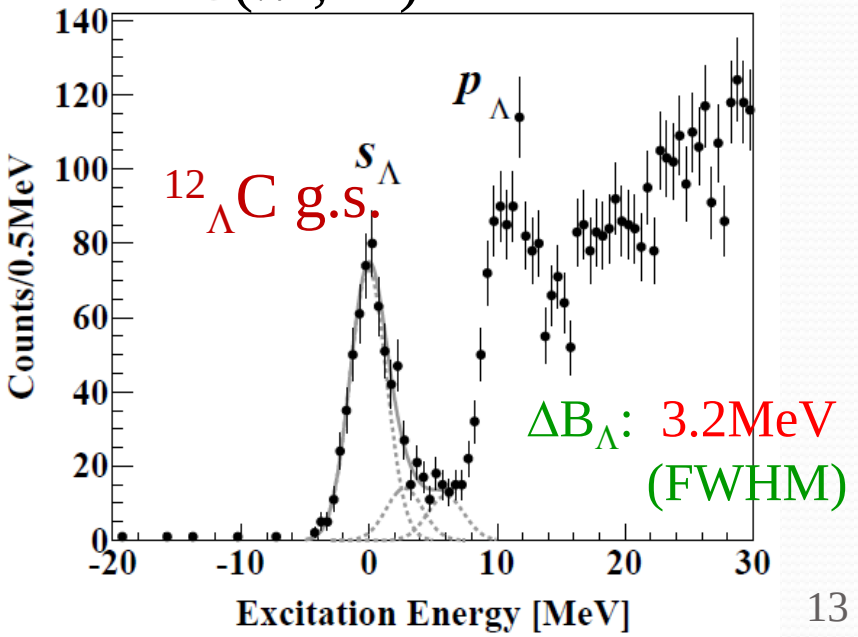
5 hours at 10M/spill

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




13+6 hours at 3M/spill

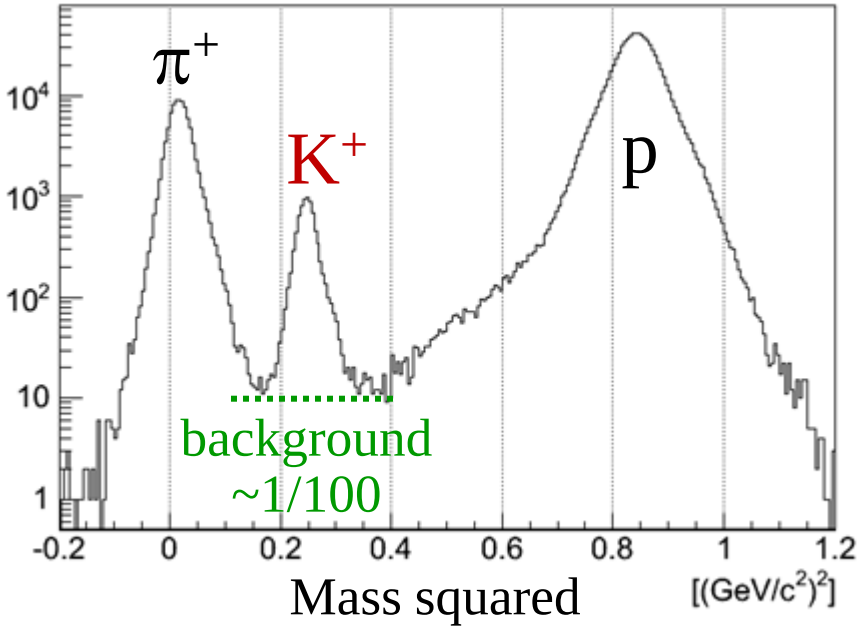
$^{12}C(\pi^+,K^+)X$



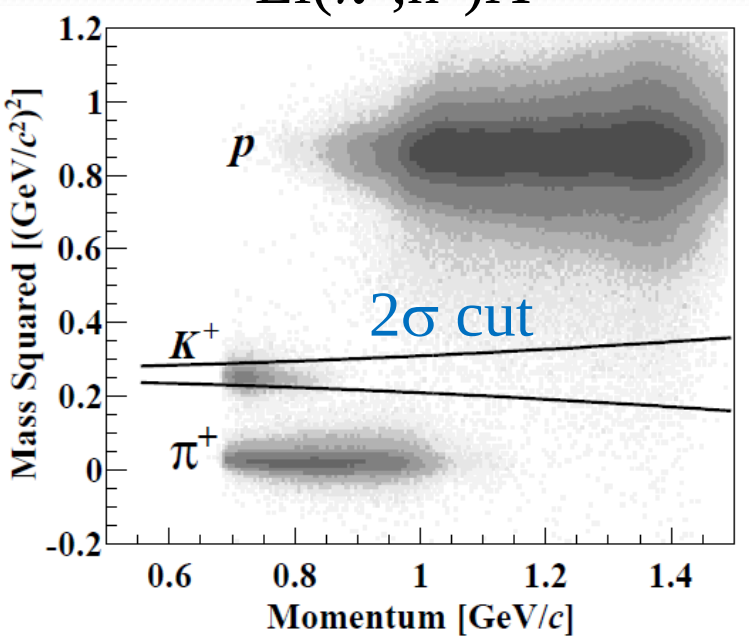
# Results of production runs

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

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

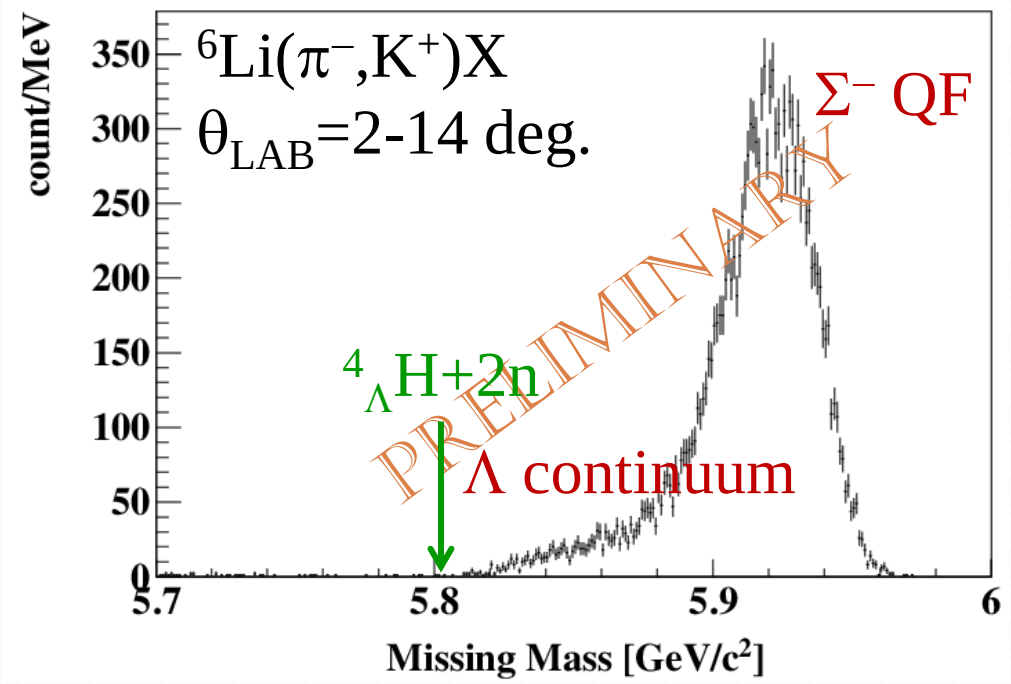



$^6$Li($\pi^-$,$h^+$)X



# Results of production runs (2)

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



# Results of production runs (3)

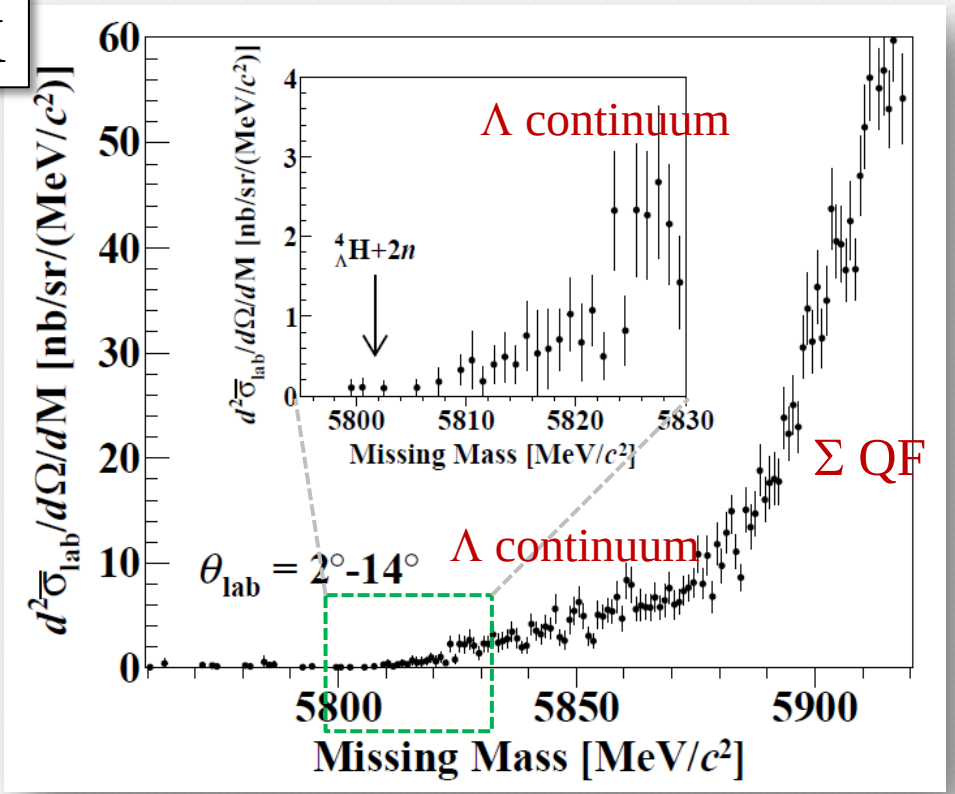
- No significant peak structure in the threshold region

$^{6}$Li($\pi^-$,$K^+$)X

Background level
0.39±0.05 event/(MeV/$c^2$)

Missing-mass resolution
3.2 MeV/$c^2$ (FWHM)

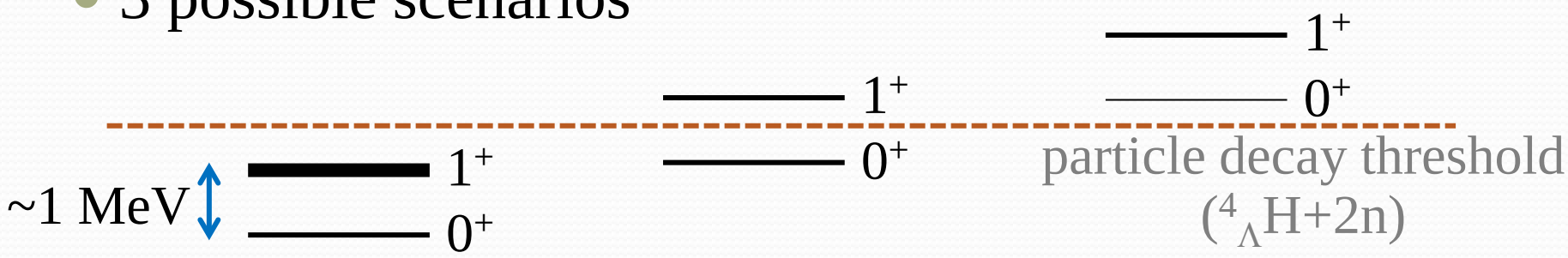
3 events around
$^{4}_{\Lambda}$H+2n threshold




- $d\sigma_{2^\circ\text{-}14^\circ}/d\Omega$ <1.2 nb/sr (90% confidence level)
- $^{6}_{\Lambda}$H structure and reaction mechanism are not simple

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

- Possible low-lying states are ${}^{6}_{\Lambda}H_{g.s.}(0^+)$ and ${}^{6}_{\Lambda}H(1^+)$
- ${}^{6}Li(1^+) \rightarrow {}^{6}_{\Lambda}H_{g.s.}(0^+)$ needs spin-flip amplitude
  - Small spin-flip amplitude in the ($\pi$,K) reaction
- 3 possible scenarios




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

- Need theoretical input of production cross sections

# Summary and outlook

- J-PARC E10
  - Study of neutron-rich Λ hypernuclei
    - Production of ${}^{6}_{\Lambda}\mathrm{H}$ and ${}^{9}_{\Lambda}\mathrm{He}$
- ${}^{6}_{\Lambda}\mathrm{H}$ production as phase-1 of E10 experiment
  - Production cross section considerably small
    - $d\sigma_{2^\circ\text{-}14^\circ}/d\Omega < 1.2$ nb/sr (90% confidence level)
    - ${}^{10}_{\Lambda}\mathrm{Li}$ case $d\sigma_{2^\circ\text{-}14^\circ}/d\Omega \sim 10$ nb/sr
  - Analyses are still in progress
    - Wider angular range (up to 20˚) and background reduction
- Future measurement (phase-2 of E10)
  - ${}^{9}_{\Lambda}\mathrm{He}$ production (in between ${}^{10}_{\Lambda}\mathrm{Li}$ and ${}^{6}_{\Lambda}\mathrm{H}$)