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SPIN2021, Matsue/Online, 21 Oct 2021

Search for the H-dibaryon near $\Lambda\Lambda$ and Ξ^-p thresholds via $^{12}C(K^-,K^+)$ reactions at J-PARC

Shin Hyung Kim (Korea Univ.)
for the J-PARC E42 Collaboration

Outline

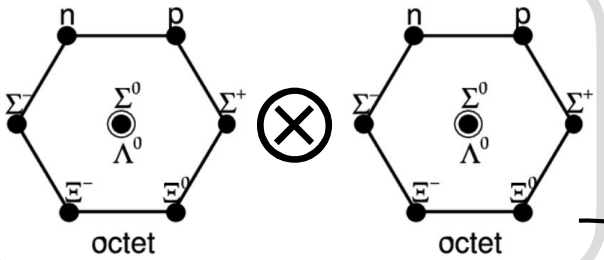
Search for the H-dibaryon near $\Lambda\Lambda$ and Ξ^-p thresholds via $^{12}C(K^-,K^+)$ reactions at J-PARC

- Introduction
  - History of H-Dibaryon Search
- J-PARC E42 Experiment
  - Experimental setup
  - Expected results
- Other physics topic
  - E42 byproducts
- Summary

Introduction

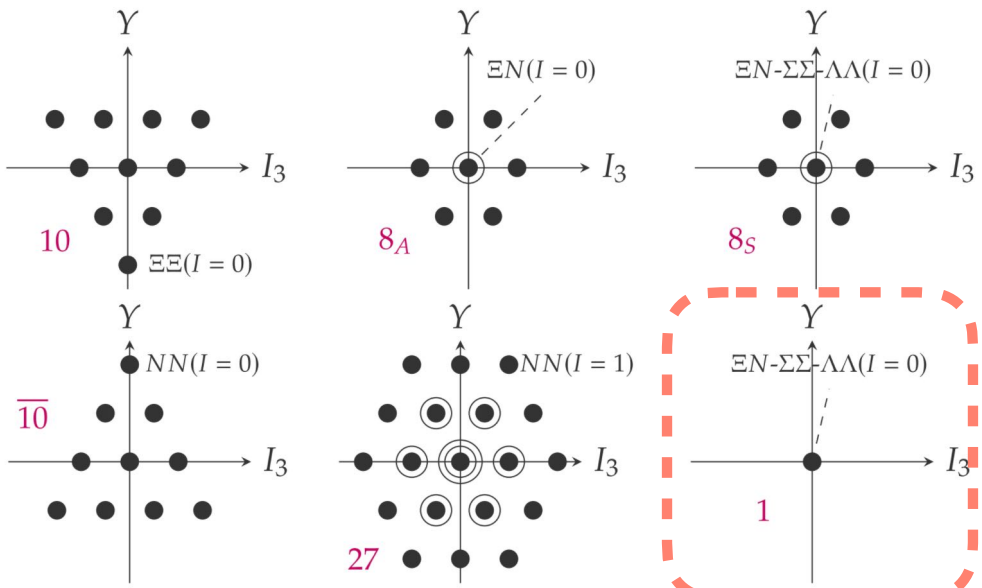
H-Dibaryon?

- SU(3) flavor singlet hexaquark state ($uuddss$, $I=0$, $J^{\pi}=0^{+}$)



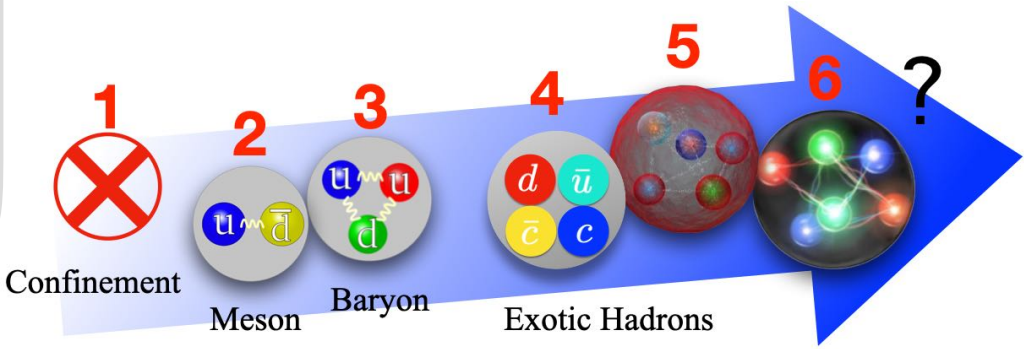
- The most promising dibaryon candidate due to QCD color-magnetic force.

Dibaryon multiplets



QCD color magnetic interaction

$$\mathcal{H}_{\text{eff}} \propto -\sum_{i\neq j} \vec{\lambda}_i \cdot \vec{\lambda}_j \vec{\sigma}_i \cdot \vec{\sigma}_j,$$



Brief History of H-Dibaryon Search

1977 First proposed by Jaffe **"Deeply bound state"**

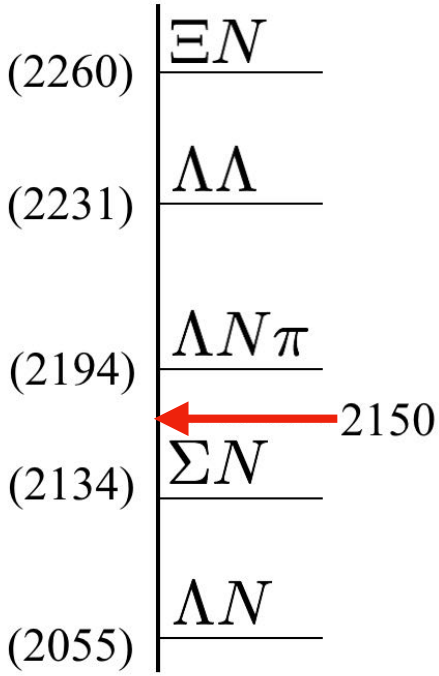
81 MeV lighter than the $\Lambda\Lambda$ threshold

VOLUME 38, NUMBER 5 PHYSICAL REVIEW LETTERS 31 JANUARY 1977

Perhaps a Stable Dihyperon*

R. L. Jaffe†
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, and Department of Physics and Laboratory of Nuclear Science,‡ Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
(Received 1 November 1976)

In the quark bag model, the same gluon-exchange forces which make the proton lighter than the $\Delta(1236)$ bind six quarks to form a stable, flavor-singlet (with strangeness of -2) $J^P = 0^+$ dihyperon (H) at 2150 MeV. Another isosinglet dihyperon (H^*) with $J^P = 1^+$ at 2335 MeV should appear as a bump in $\Lambda\Lambda$ invariant-mass plots. Production and decay systematics of the H are discussed.

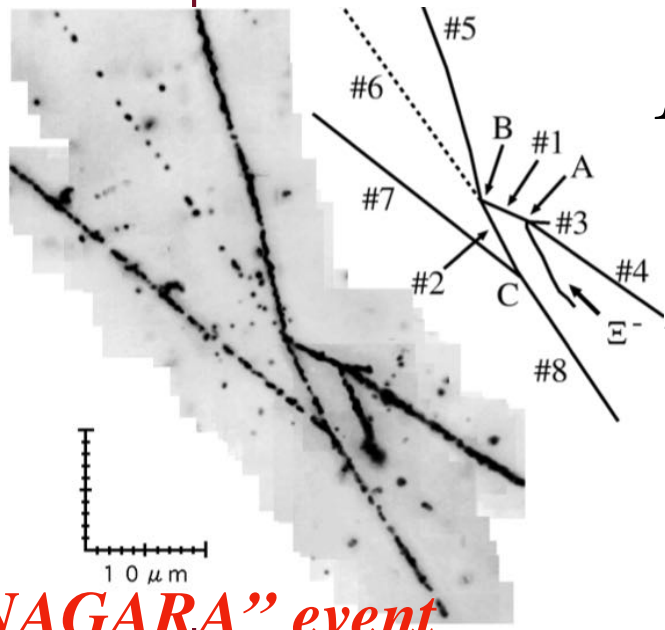


Many **experimental** attempts to find H
Many **theoretical** model calculations to predict the H mass

Brief History of H-Dibaryon Search

1977 First proposed by Jaffe "Deeply bound state"

2001 Mass constraint from ${}_{\Lambda\Lambda}{}^{6}$He ($B_{\Lambda\Lambda}$ ~7 MeV)



"NAGARA" event

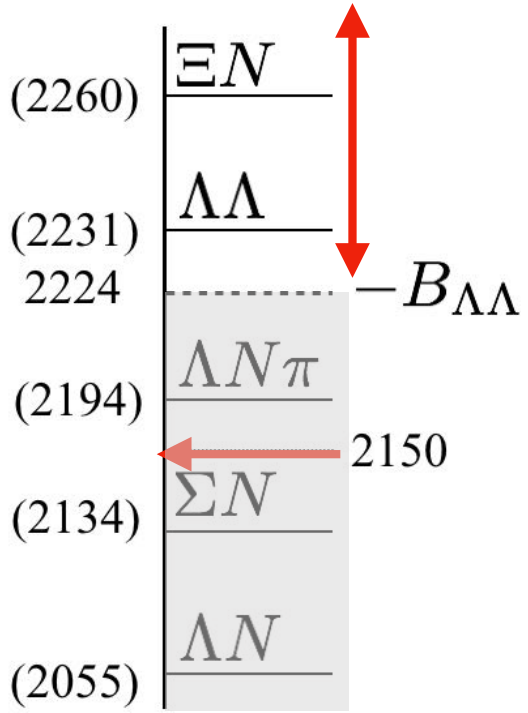
Phys. Rev. Lett. 87, 212502 (2001)

$$M_H > 2M_\Lambda - B_{\Lambda\Lambda}$$

Lower limit of M_H
2223.7 MeV/c^2 (90% CL)

Weakly bound state?
Resonance?

J-PARC E07 (2017)
x10 data coming soon!



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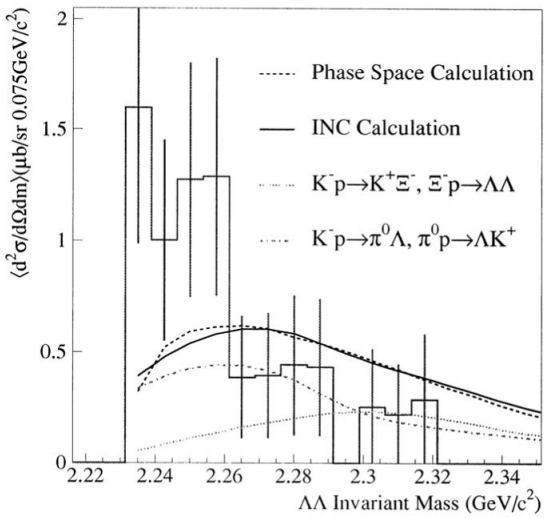
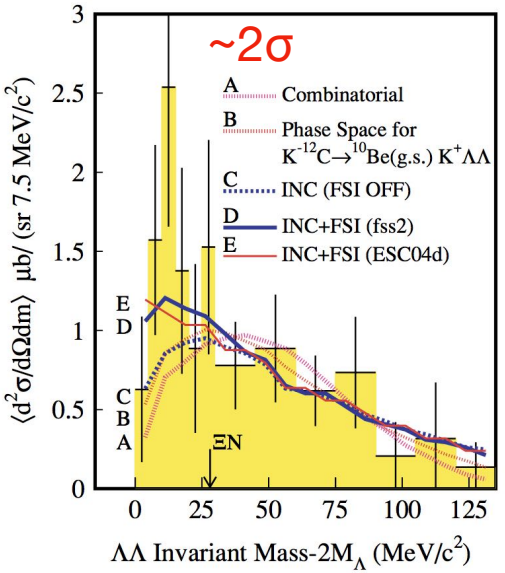
1998,2007 Observed enhancement near $\Lambda\Lambda$ threshold

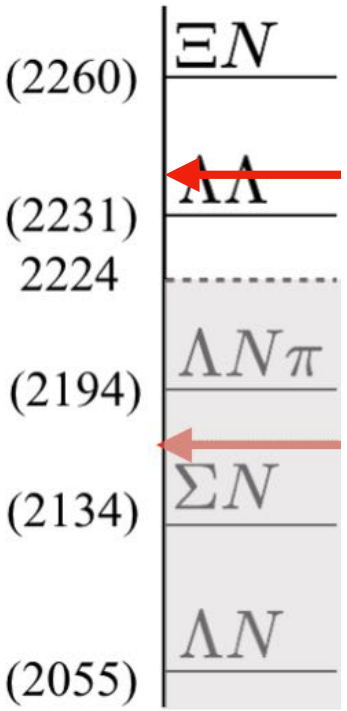


Phys. Lett. B444, 267 (1998)

2.1 μb/sr (90% CL)



Phys. Rev. C75, 022201 (2007)



Brief History of H-Dibaryon Search

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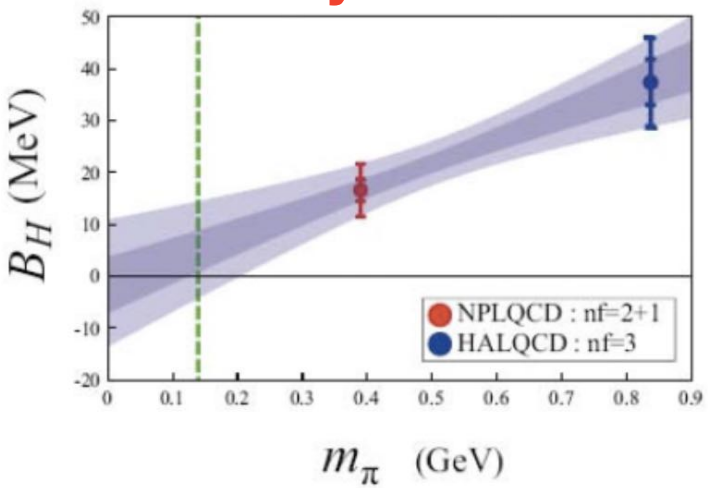
1998,2007 — Observed enhancement near $\Lambda\Lambda$ threshold

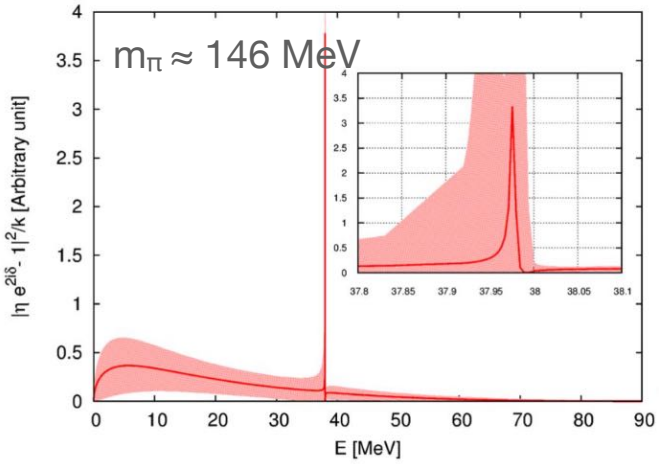
2011,2018 — LQCD predictions

Loosely bound state?

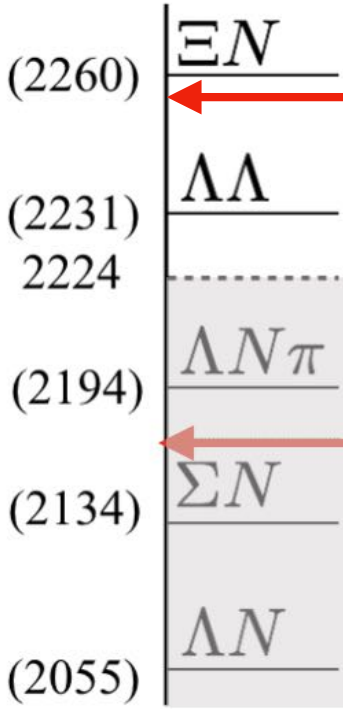


Phys. Rev. Lett. 106, 162001 (2011)

Sharp peak just before ΞN threshold?



K. Sasaki for the HAL Collab. (2018)



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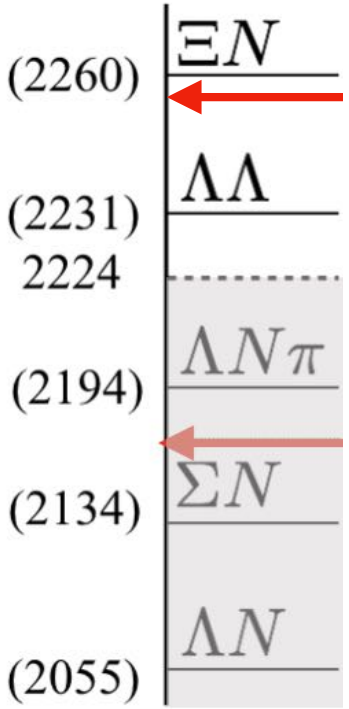
⋮

No evidence for H in high-energy e^+e^-, pp, and AA experiments

2019 ALICE supporting the presence of strong, attractive $\Xi^-\mathrm{p}$ interaction:

PRL 123, 112002 (2019)



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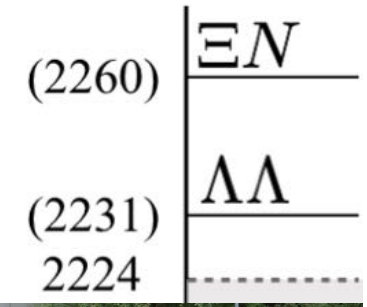
⋮ — No evidence for H in high-energy e^+e^-, pp, and AA experiments

2019 — Attractive $\Xi^-\mathrm{p}$ interaction in HIC

2021 — **E42 @J-PARC**

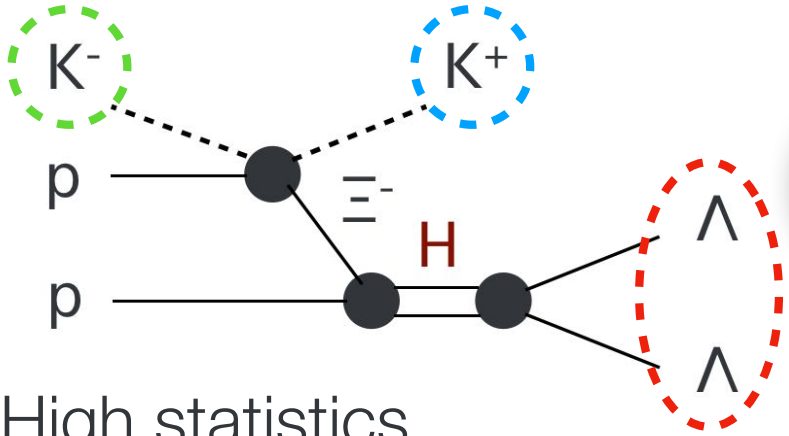


E42 Completed June 29, 2021

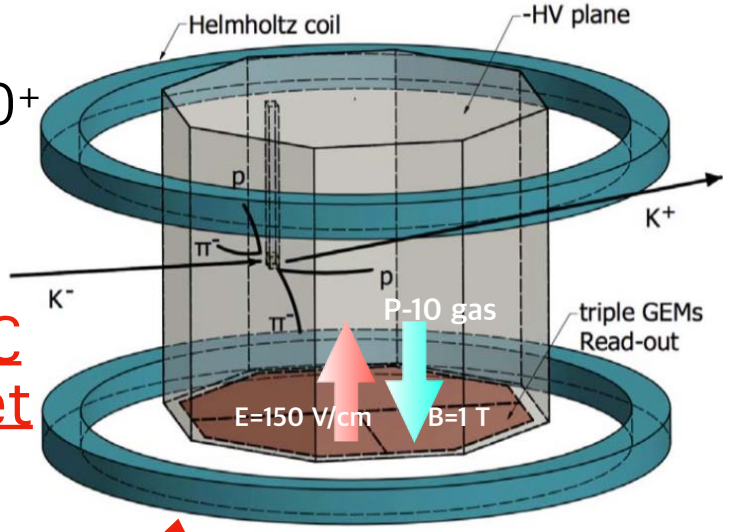
J-PARC E42 Experiment

J-PARC E42 Experiment

- Search for *H*-dibaryon via $^{12}C(K^-,K^+)$ reactions at 1.8 GeV/c

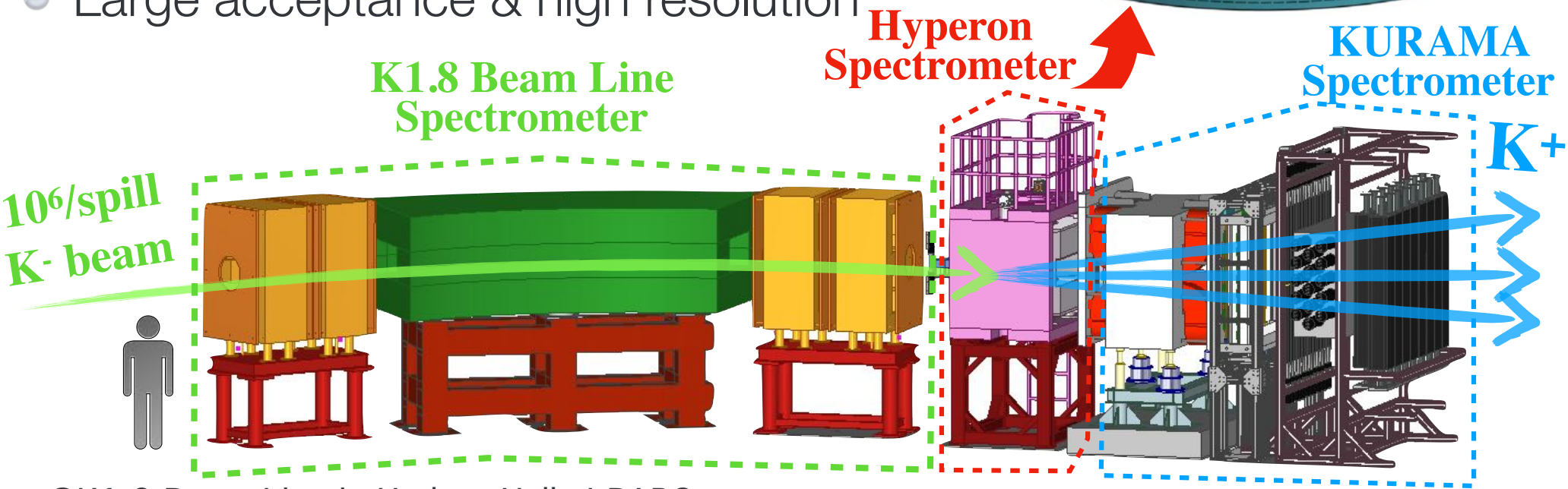


? *uuddss*
I=0, $J^\pi=0^+$



HypTPC
SC Magnet

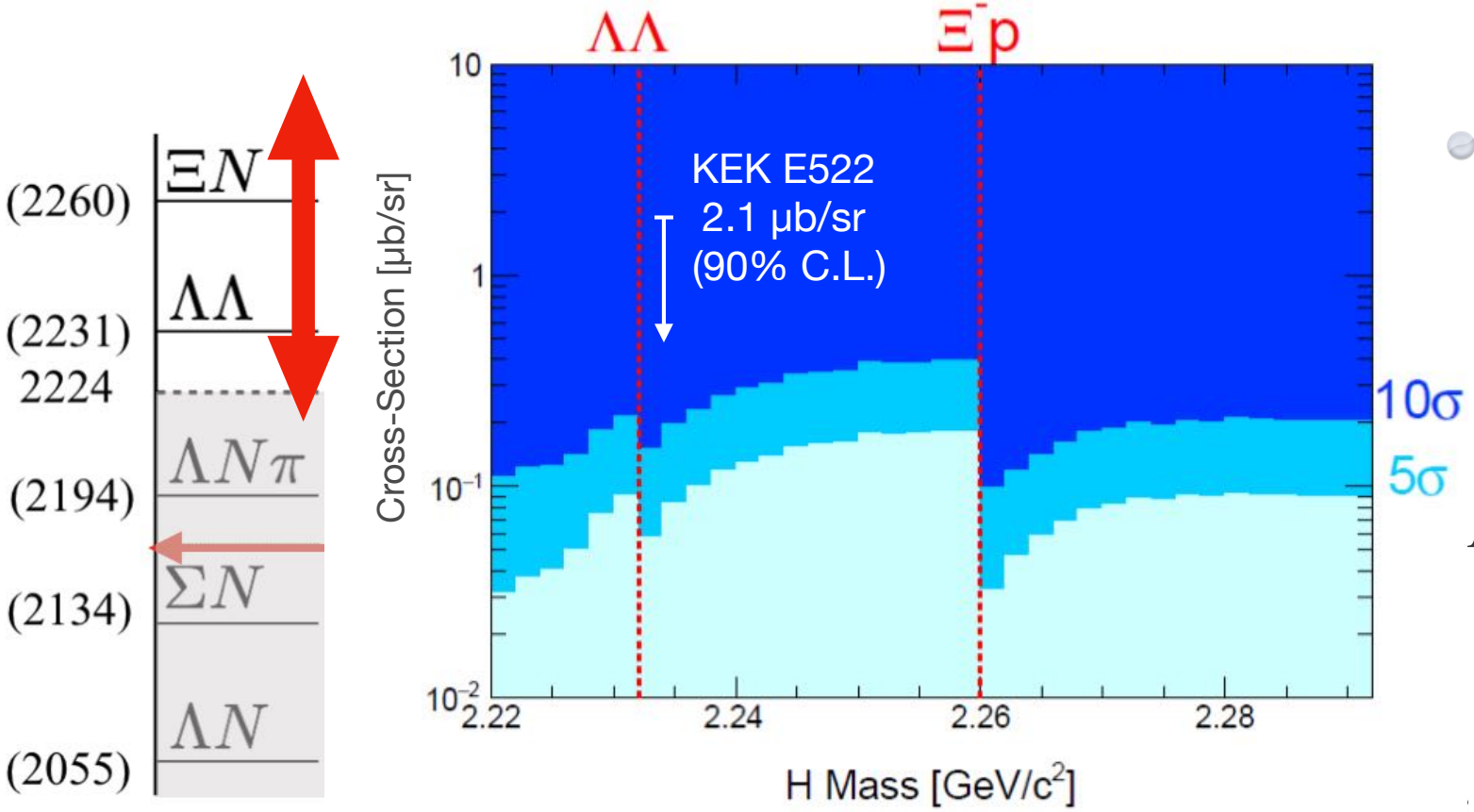
- High statistics
- Large acceptance & high resolution



@K1.8 Beam Line in Hadron Hall, J-PARC

Experimental Sensitivity to H Mass

- The sensitivity is good enough to cover a broad range of the H-dibaryon mass from **the $\Lambda\Lambda$ bound state** to **the unbound region above the Ξ^-p mass threshold**.



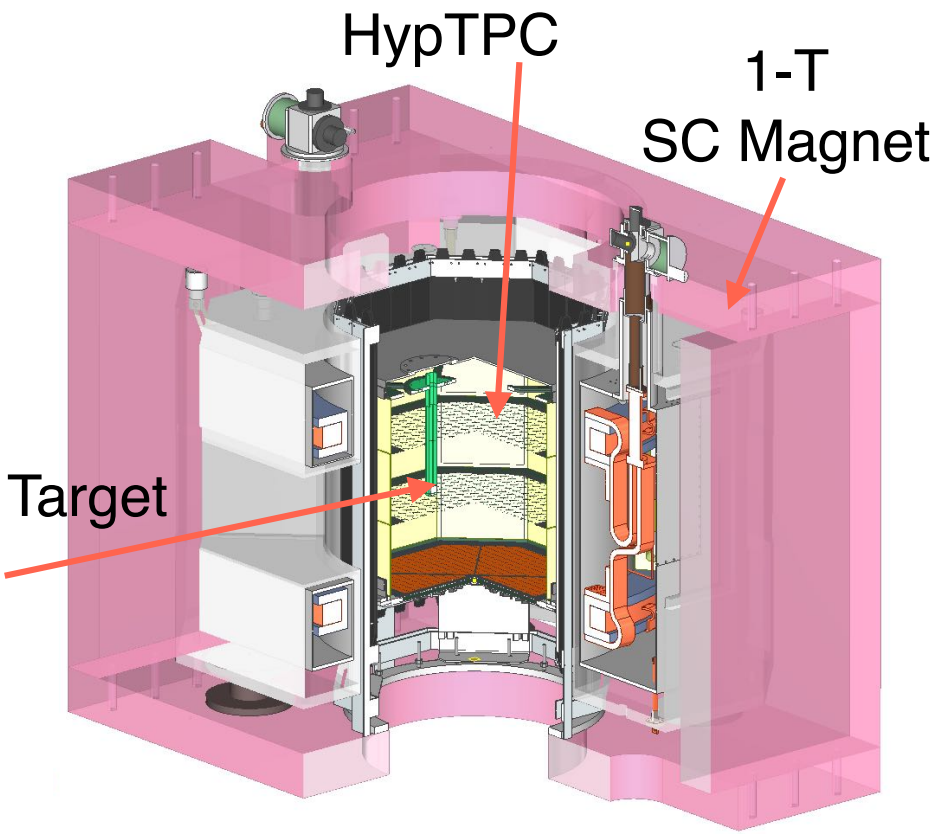
- Significance:

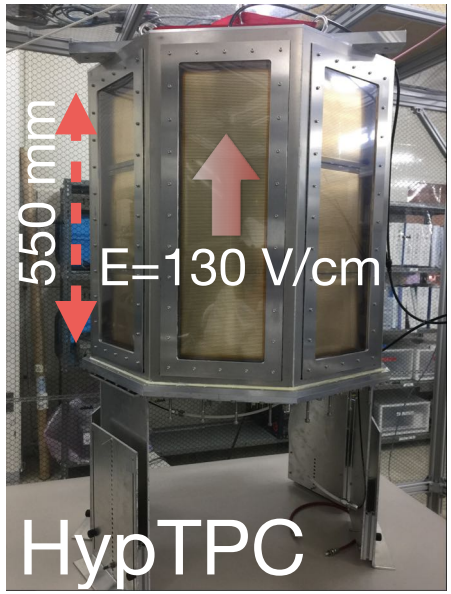
$$\frac{S}{\sqrt{S+B}}$$

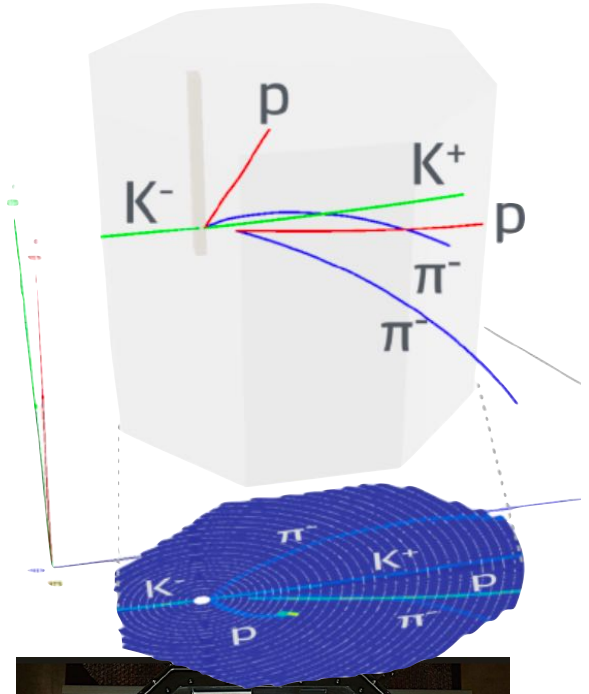
B: INC model w/ 7.6 μb/sr

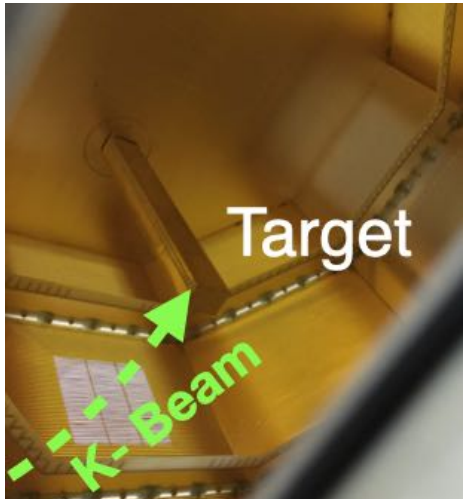
Hyperon Spectrometer

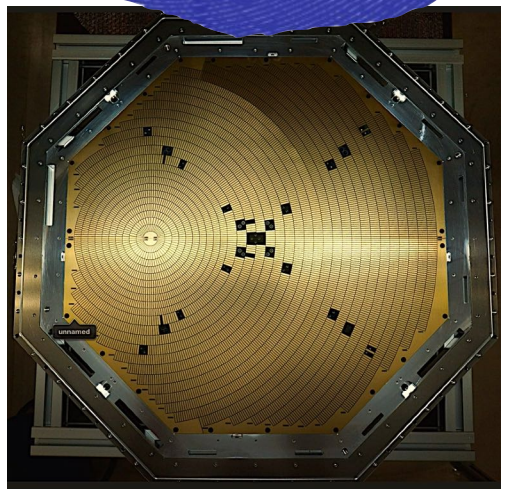
- Detect all charged particles from $^{12}C(K^-, K^+)$ reactions
- Target inside the HypTPC drift volume



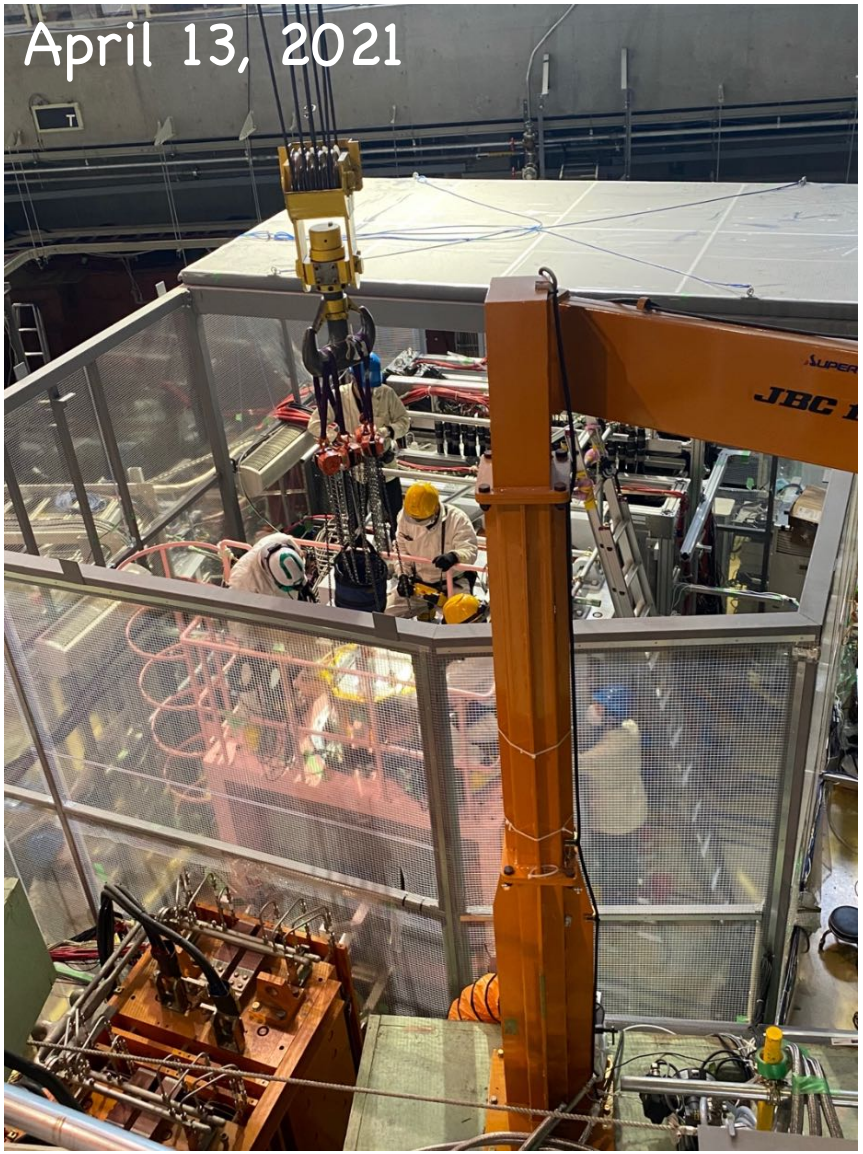


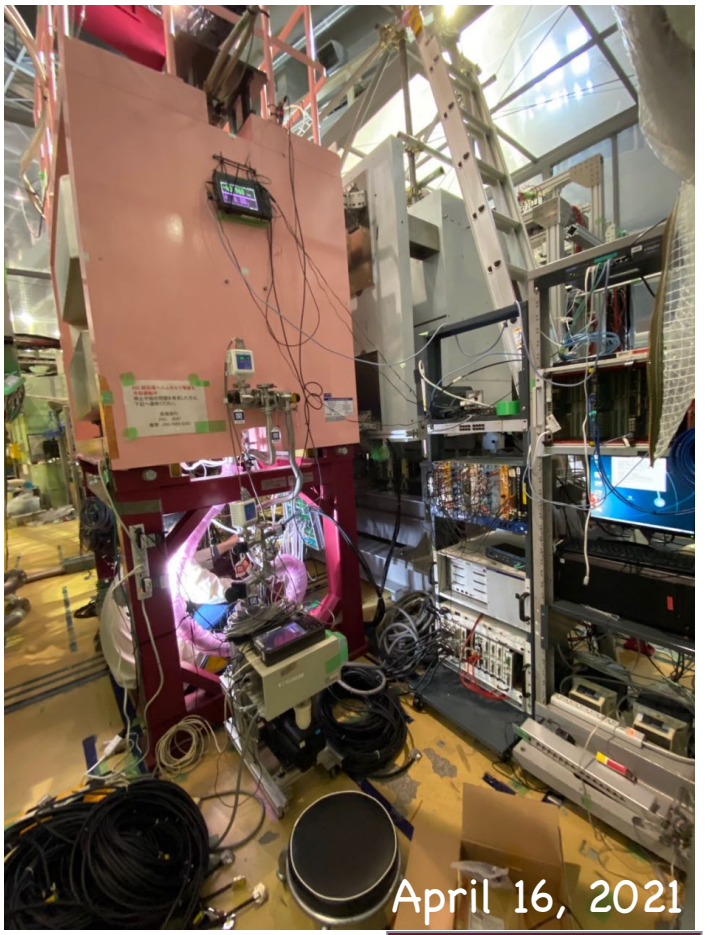






Hyperon Spectrometer at K1.8 Beam Line





E42 Collaboration

J.K. Ahn (*spokesperson*), **S.H. Kim**, S.W. Choi, W.S. Jung, B.M. Kang, J.W. Lee, S.B. Yang, M. Fujita, S. Hasegawa, **Y. Ichikawa** (*co-spokesperson*), K. Imai , H. Sako, S. Sato, K. Tanida, T. Takahashi, M. Ukai, T. Yamamoto, **S. Hayakawa**, Y. Ishikawa, S. Kajikawa, K. Kamada, T. Kitaoka, T. Morino, F. Oura, T. Sakao, M. Saito, H. Tamura, S. Wada, T. Harada, S.H. Hwang, K. Hicks

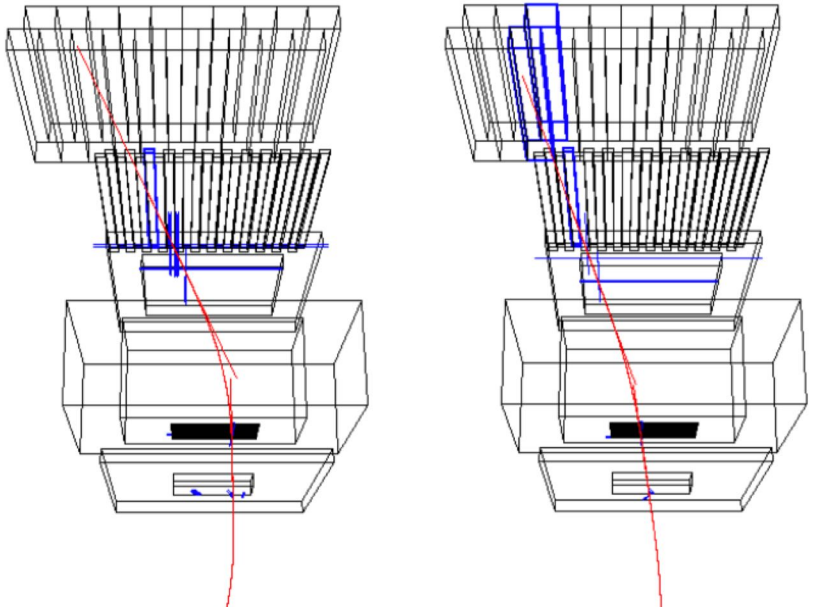
Ph.D. candidates and **core members**

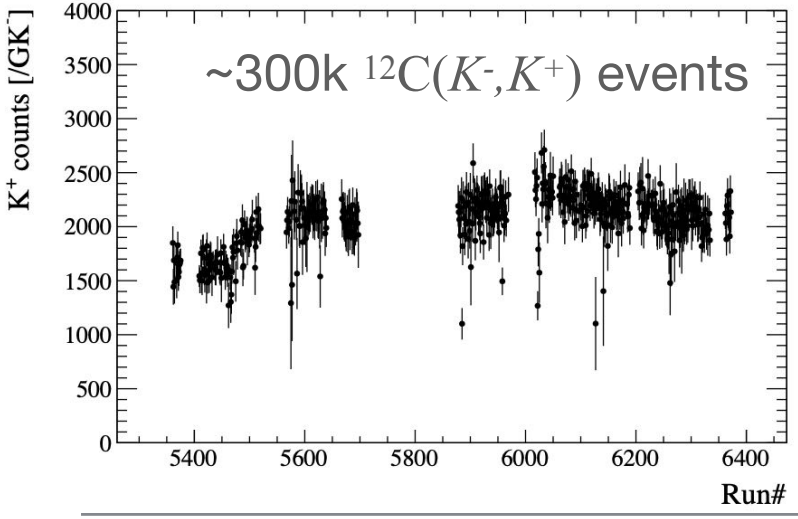
Korea Univ / JAEA / KEK / Tohoku Univ / Kyoto Univ/ KRISS / Ohio Univ

E42
Completed
June 29, 2021

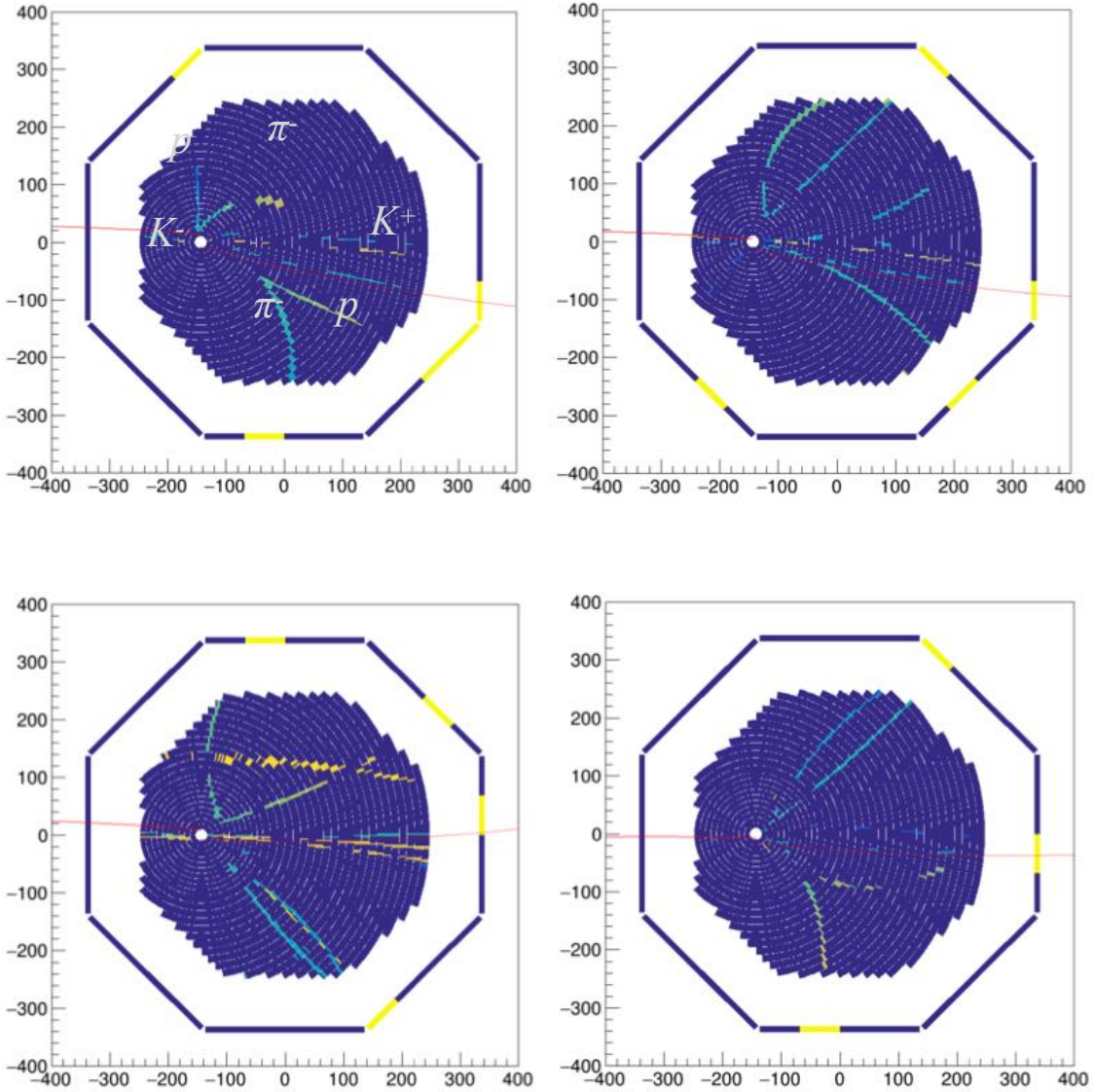
Online Event Displays

- KURAMA Spectrometer

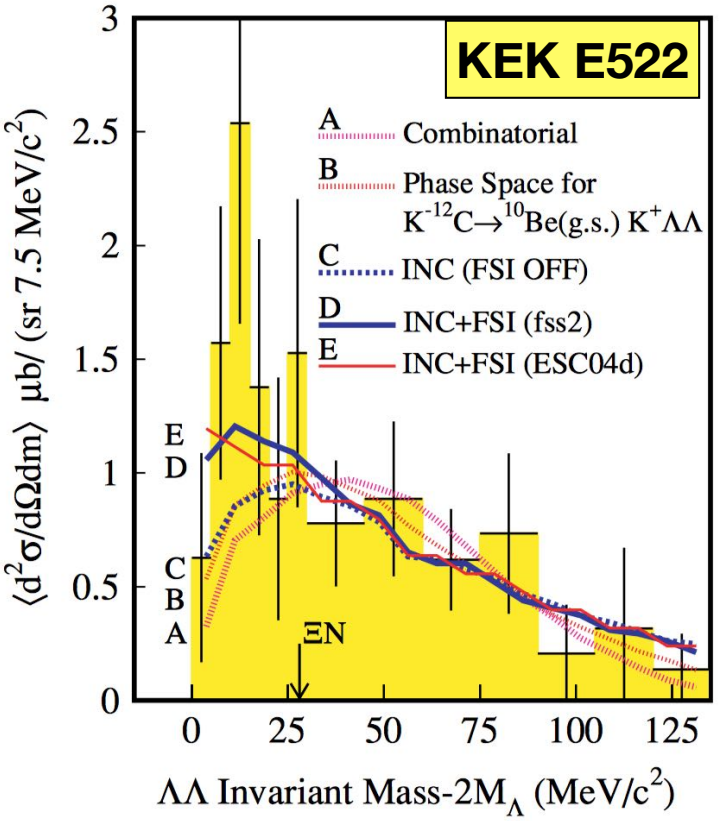


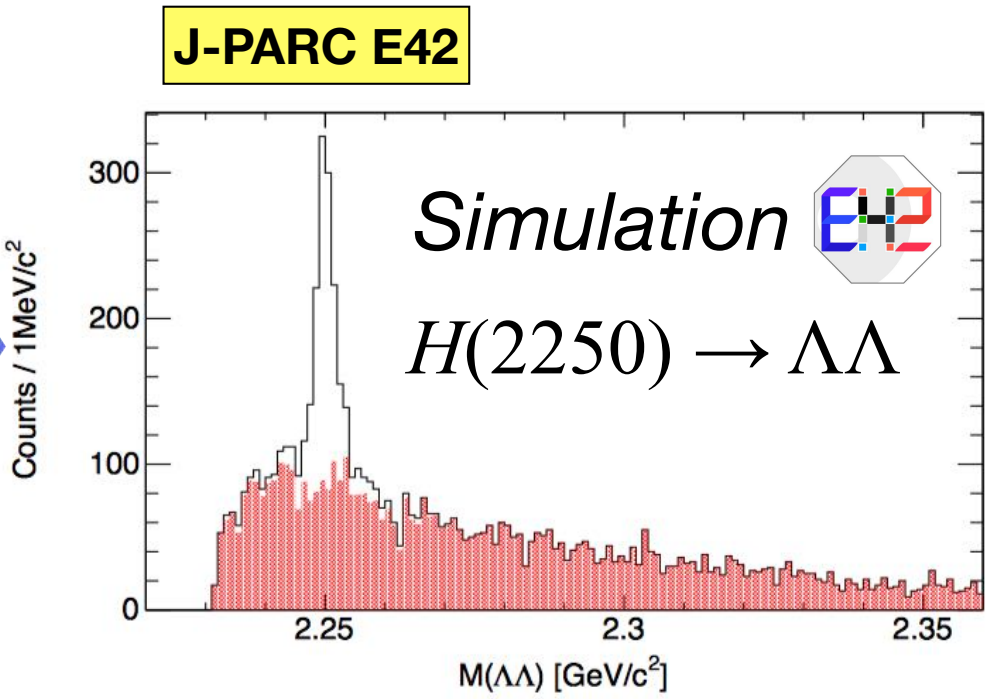


- Hyperon Spectrometer



Expected Results

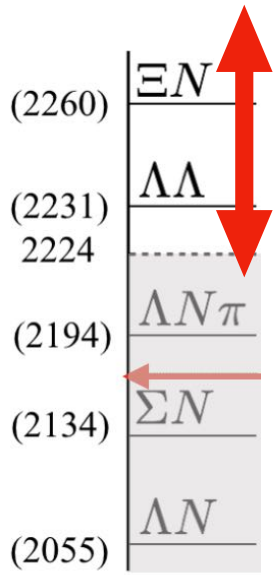


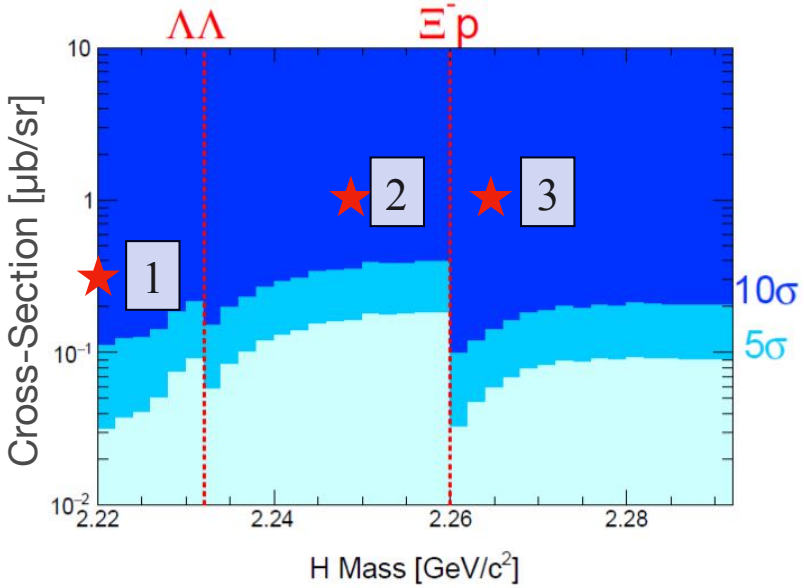


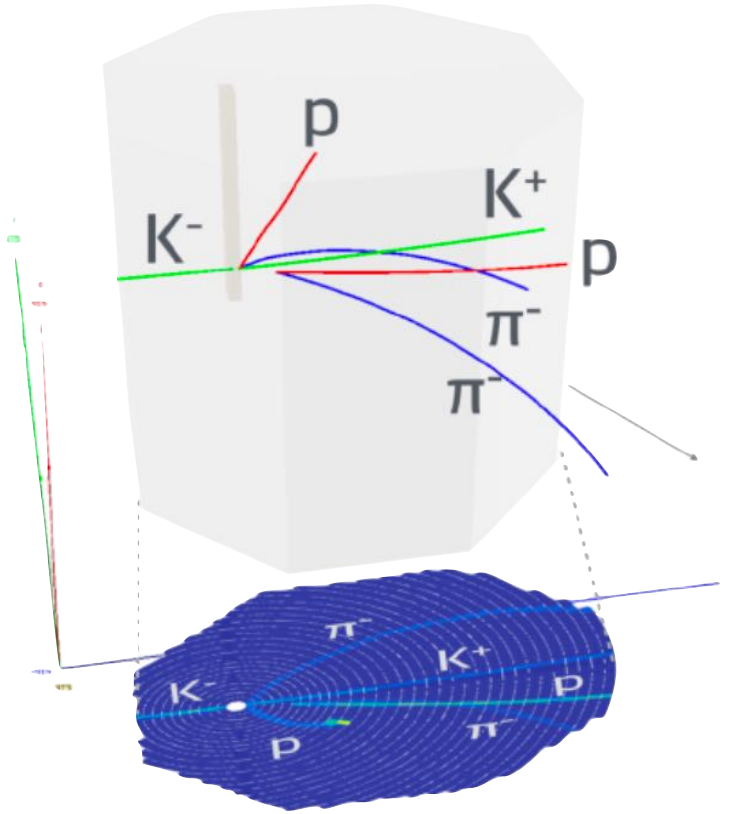
$\sigma_{\Delta M}$ ~5 MeV
90 $\Lambda\Lambda$ events
$d\sigma/d\Omega(\Lambda\Lambda)$=7.6 μb/sr
$d\sigma/d\Omega(H)$=2.1 μb/sr
(90% CL)

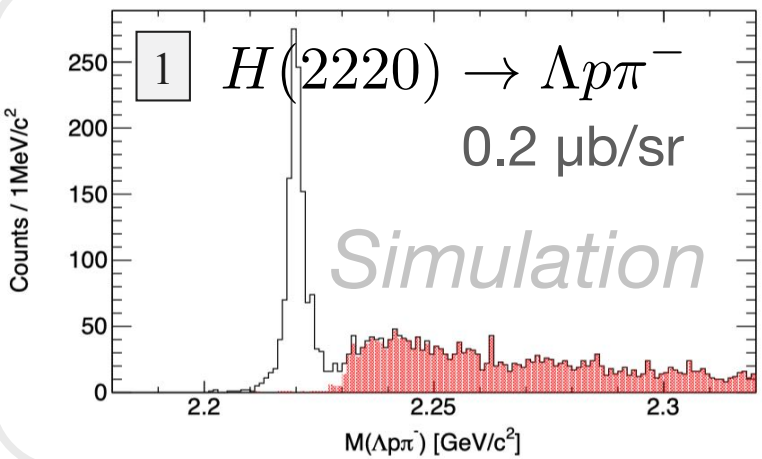
$\sigma_{\Delta M}$ ~1 MeV
6.2×10^3 $\Lambda\Lambda$ events
$d\sigma/d\Omega(\Lambda\Lambda)$=7.6 μb/sr
$d\sigma/d\Omega(H)$=1.0 μb/sr

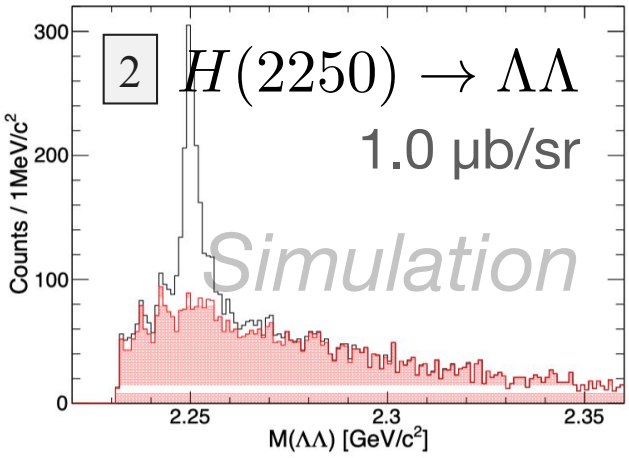
Expected Results II

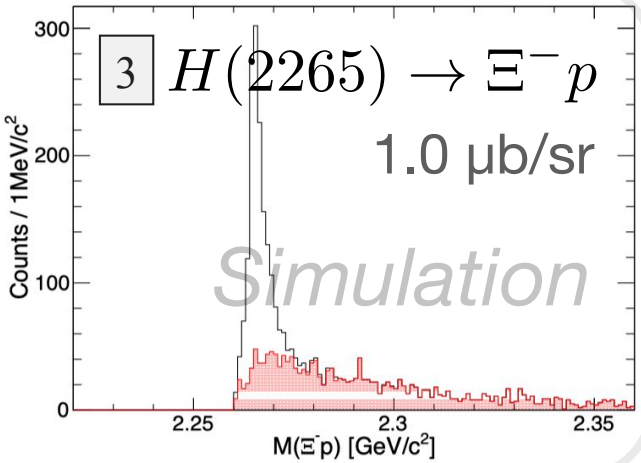






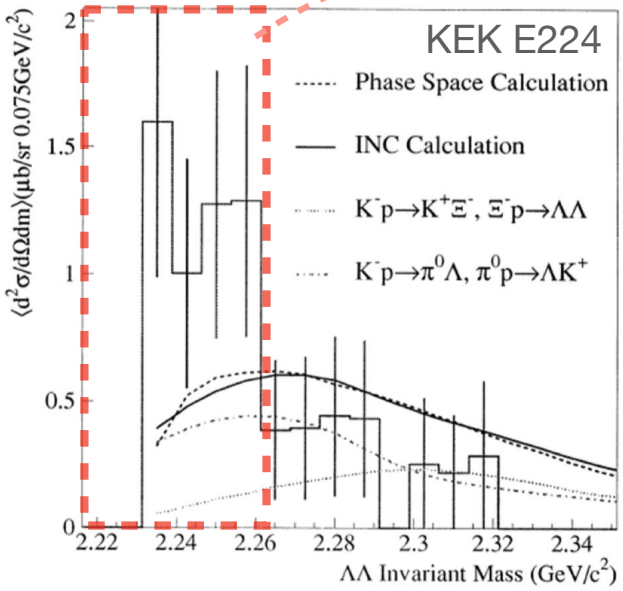


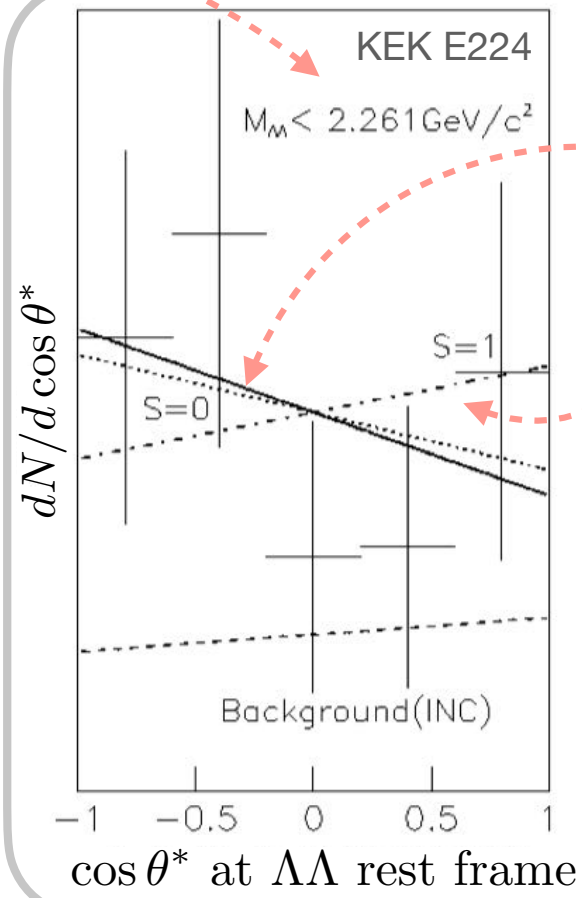




Spin Analysis

- Spin analysis of two Λs would help an experimental confirmation of the existence of a spin-singlet H-dibaryon.

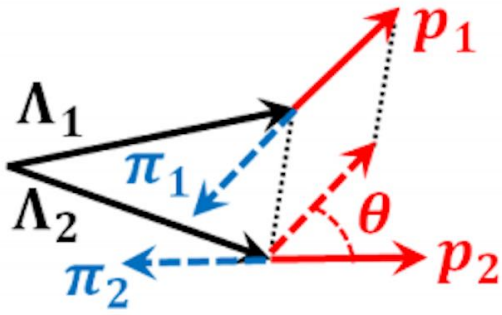




$$\left.\frac{dN}{d\cos\theta^*}\right|_{S=0} = 1 - \alpha_\Lambda^2 \cdot \cos\theta^*$$

$$\left.\frac{dN}{d\cos\theta^*}\right|_{S=1} = 1 + \frac{1}{3}\alpha_\Lambda^2 \cdot \cos\theta^*$$

θ^*: the angle between two decay protons in the $\Lambda\Lambda$ rest frame



Pays. Lett. B, 352, 162 (1995)

J Korean Phys Soc, 45, 323 (2004)

Other Physics Topic

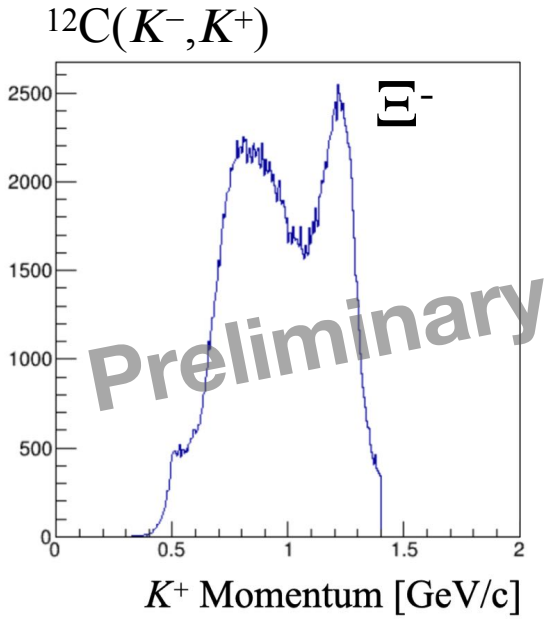
Ξ^- / Ξ^{*-} in (K^-,K^+) Reaction at 1.8 GeV/c

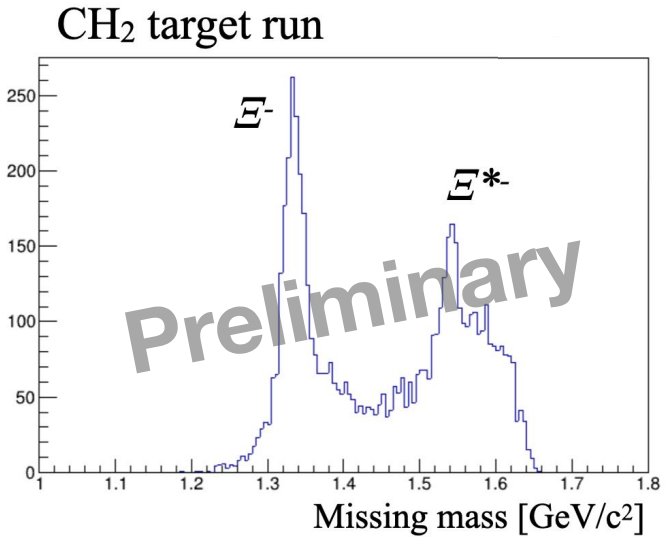
- Determine Ξ^- Polarization (P_Ξ)
- Search for $\Xi^- \rightarrow p\pi^-\pi^-$ rare decay ($\Delta S=2$)

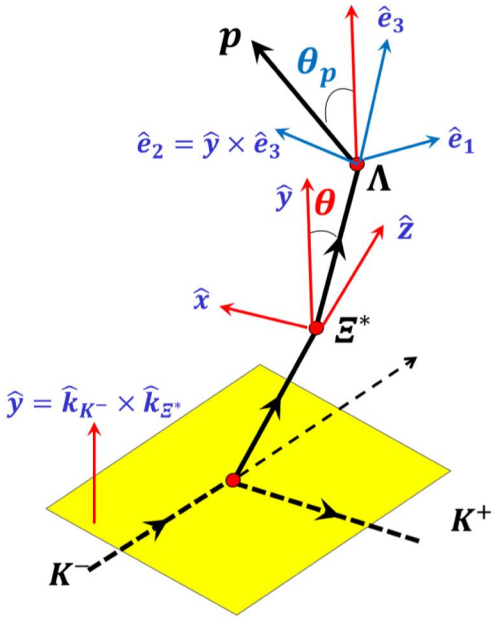
$$\frac{\Gamma(\Xi^- \rightarrow p\pi^-\pi^-)}{\Gamma(\Xi^- \rightarrow \Lambda\pi^-)} < 4 \times 10^{-4}$$ with 6,200 events PRD 10, 3545 (1974)

- Secondary Ξ^- interactions: $\Xi^-p \rightarrow \Lambda\Lambda$, $\Xi^-p \rightarrow \Xi^-p$
- $d\sigma/d\Omega$ for $K^-p \rightarrow K^+\Xi^{*-}(1530)$

K18 BL
KURAMA
HypTPC





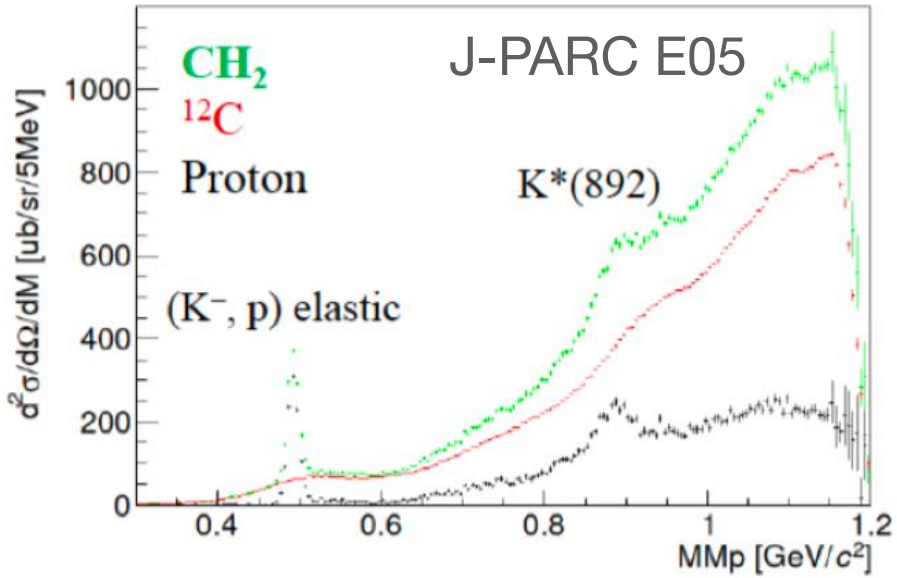


$K^{*-}(892)$ In-Medium Mass Shift

- $^{12}C(K^-,p)K^{*-}(892)\ X$,
  $K^{*-}(892) \rightarrow K^0\,\pi^-$, $K_S^0 \rightarrow \pi^+\,\pi^-$

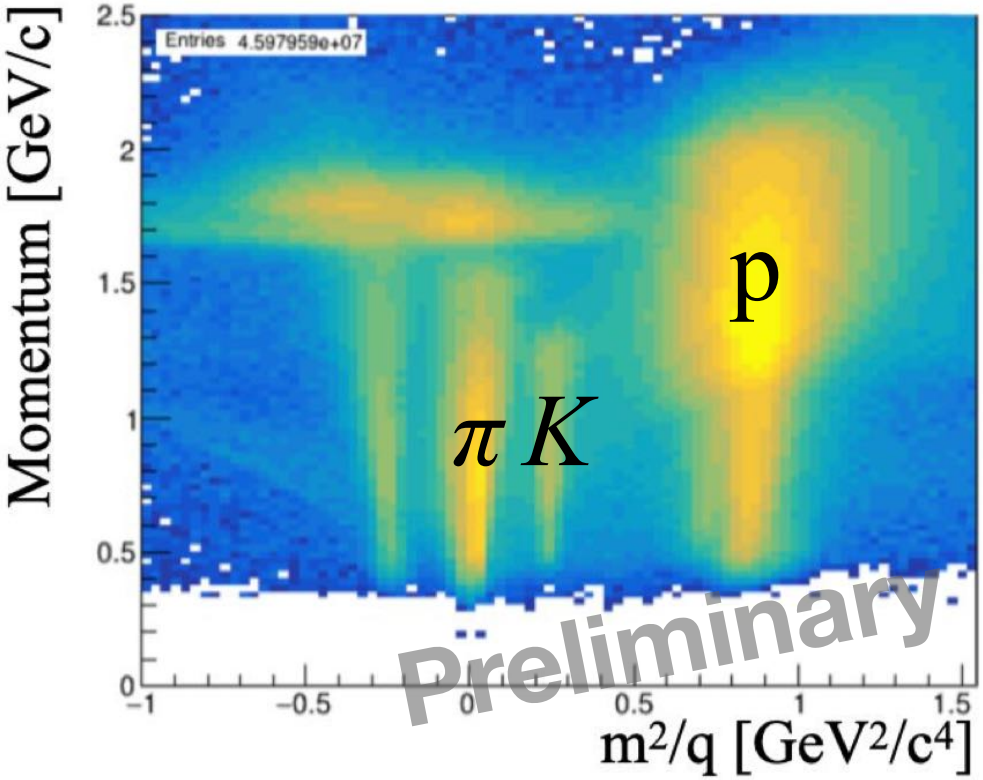
K18 BL
KURAMA
HypTPC

The (K^-, p) spectra for CH_2 and carbon targets.
(Assuming that proton at reset is a target.)



PDG value K*(892)
- Mean: 891.6±0.26 MeV/c²
- **Γ: 50.8±0.9 MeV**

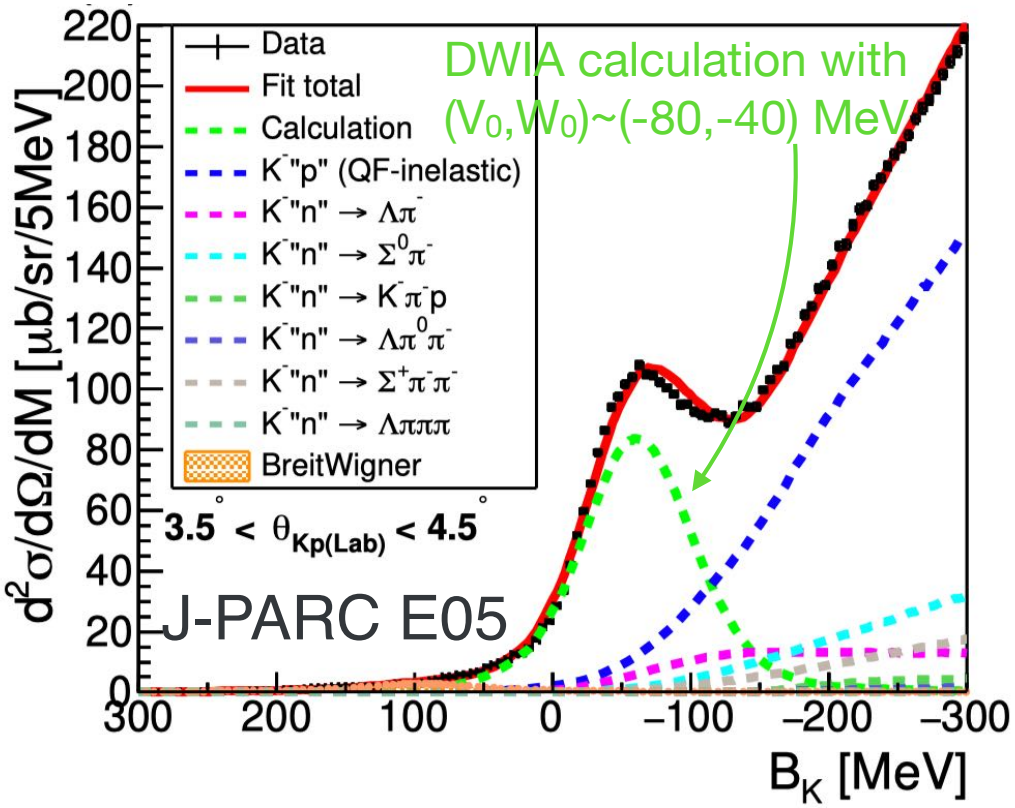
R. Honda, QNP2018

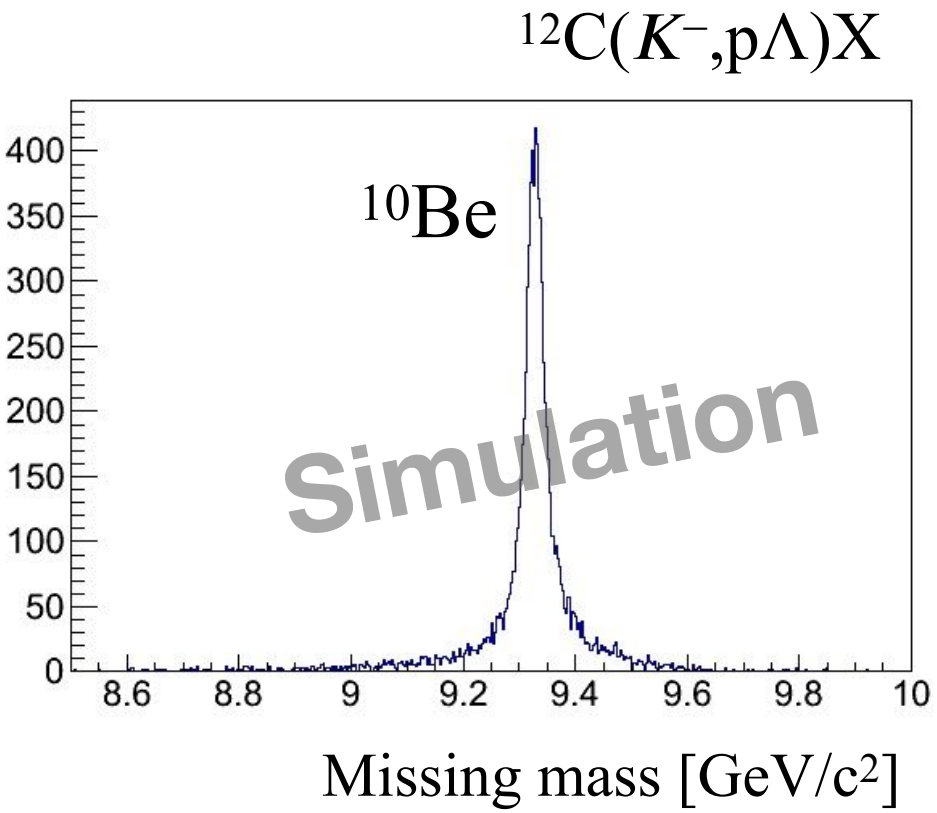


KN Interaction with Kaonic Nuclei

- K^- ^{12}C → p $^{11}_{K^-}$Be, $^{11}_{K^-}$Be → Λ ^{10}Be

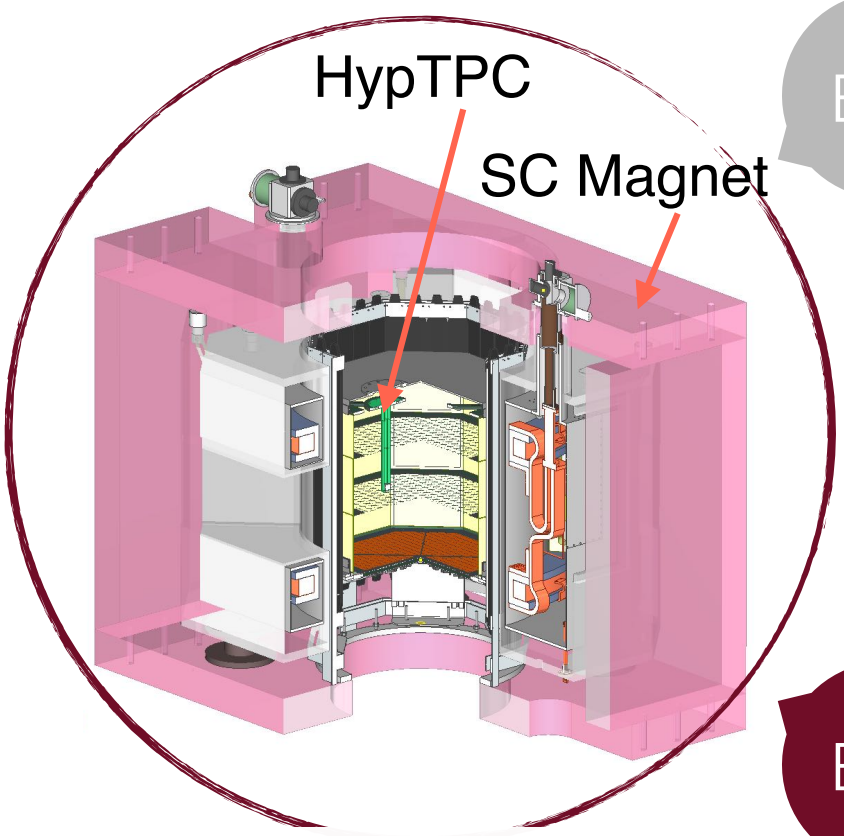
K18 BL
KURAMA
HypTPC





Y. Ichikawa et al. Prog. Theor. Exp. Phys. 12, 123D01 (2020)

J-PARC Hadron Experiments with HypTPC



E42

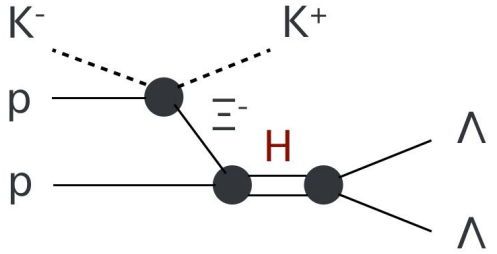
E45

E72

<Hyperon Spectrometer>

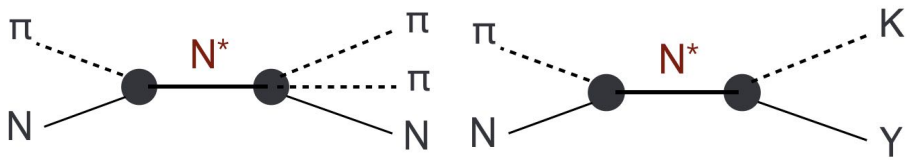
- Main tracking device

H-Dibaryon Search



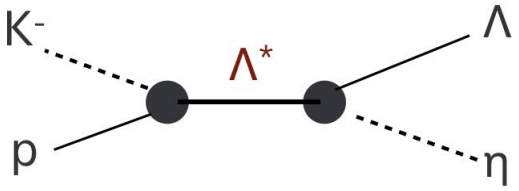
J.K. Ahn et al., J-PARC Proposal E42

N* Baryon Spectroscopy



H. Sako et al., J-PARC Proposal E45

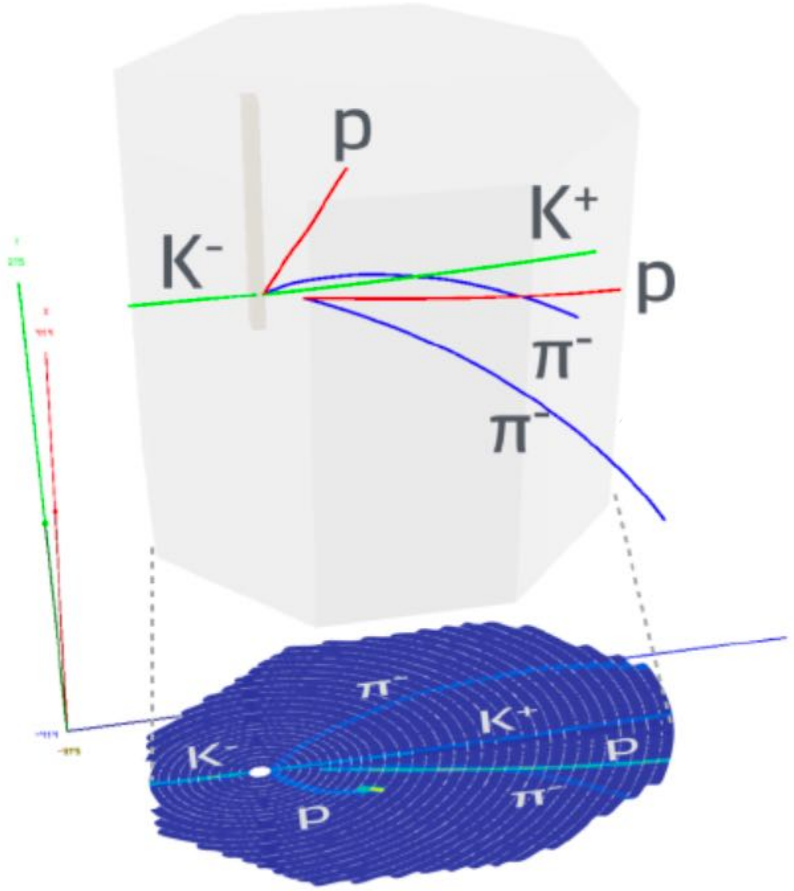
New Λ* Resonance Search near Λη Threshold



K. Tanida et al., J-PARC Proposal E72

Summary

- The J-PARC E42, which was dedicated to search for the H-dibaryon, was just completed and data analysis is on-going.
- We have collected two orders of magnitude more statistics for $\Lambda\Lambda$ production in (K^-,K^+) reaction than measured ever before.
- The E42 opens many other physics opportunities such as Ξ/Ξ* production processes in the (K^-,K^+) reaction, and HypTPC awaits new hadron physics program at J-PARC.



Stay tuned!