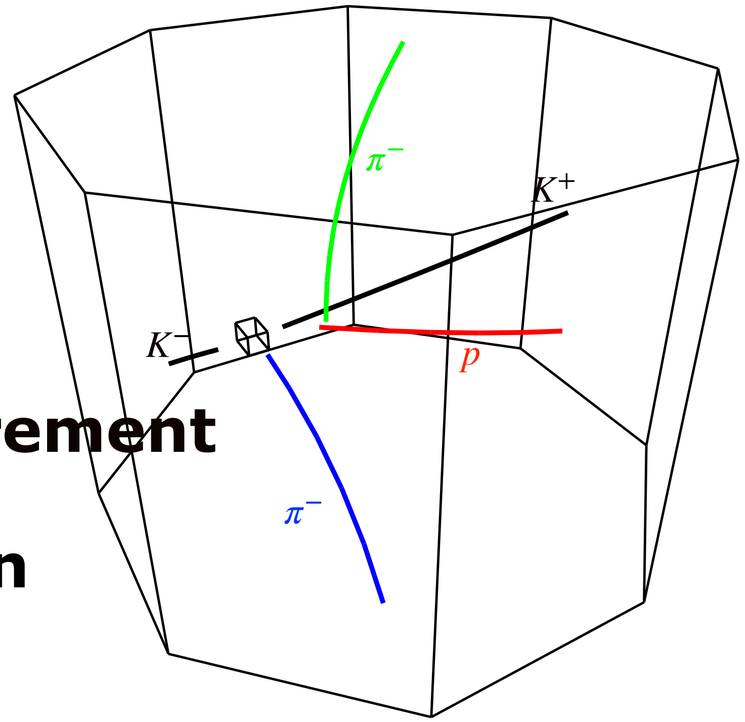
Production of double-strangeness systems near the threshold in the $^{12}\mathrm{C}(K^-, K^+)X$ reaction at 1.8 GeV/c

Woo Seung Jung (Korea University)
for the J-PARC E42 Collaboration

Outline

- Introduction to **J-PARC E42** searches H-dibaryon
- ΞN **Interaction study** using **HypTPC**
- Preliminary results on **the cross-section measurement of elementary processes in** $^{12}\mathrm{C}(K^-, K^+)X$ **reaction**

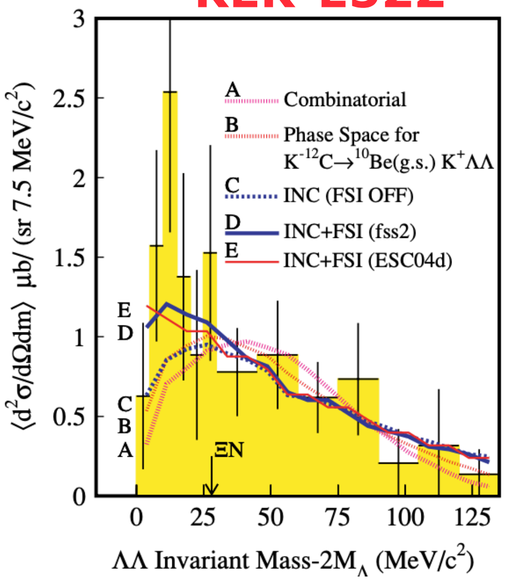


New experiment J-PARC E42 searches H-dibaryon

H-dibaryon search via $^{12}\mathrm{C}(K^-, K^+)$ reaction

- SU(3) flavor-singlet dibaryon consisting of uuddss
- Invariant-mass measurement of $\Lambda\Lambda$ and $\Xi^- p$ systems with HypTPC
- Collected 0.3 M (K^-, K^+) reaction data

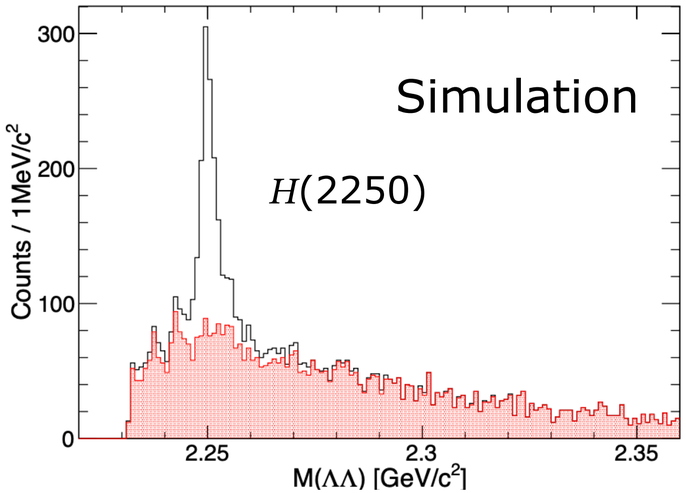
KEK-E522



$d\sigma/d\Omega_L(\mathbf{H}) = 2.1\ \mu$b/sr (90 % C.L.)

*C. J. YOON et al. PHYSICAL REVIEW C 75, 022201(R) (2007)

J-PARC E42



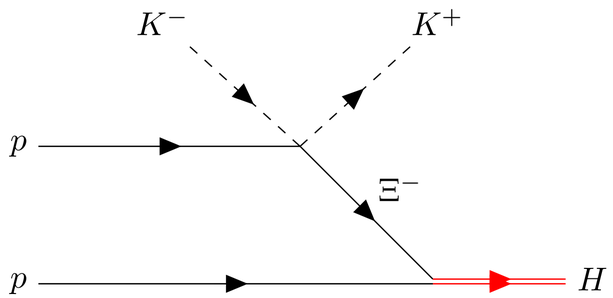
High statistics and better resolution

J-PARC E42:Study of Ξ^--nucleus Interaction for $^{12}\mathrm{C}(K^-, K^+)$ Reaction

H-dibaryon search via $^{12}\mathrm{C}(K^-, K^+)$ reaction

- Recent researches including Lattice QCD calculation indicate an attractive ΞN potential with a weak ΞN-ΛΛ coupling

*K. Sasaki et al. / Nuclear Physics A 998 (2020) 121737

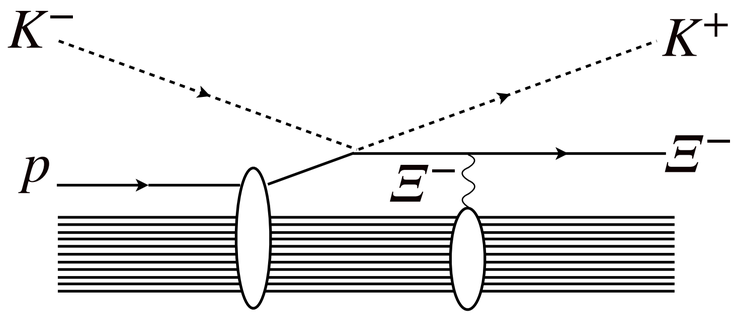


J-PARC E42 : Measurement of all charged decays from $^{12}\mathrm{C}(K^-, K^+)X$ reaction with high statistics

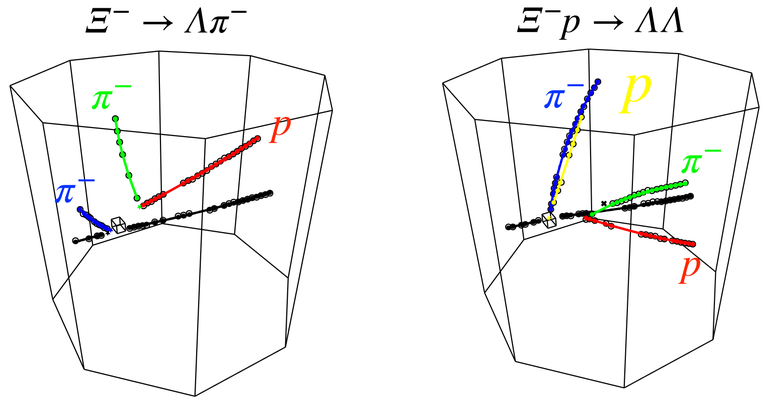
- E42 data is valuable for studying ΞN interaction.

  Ξ^- escaping? charge exchanging?

  or conversion after reacting with other nucleus?



Each process can be reconstructed using **Time-projection chamber(HypTPC)!**



aswe11@korea.ac.kr

Study of Ξ^--nucleus Potential

Ξ^--nucleus Potential

$$U_{\Xi^-} = [V_0^{\Xi} + iW_0{}^{\Xi} g(E)] f(r)$$

where,

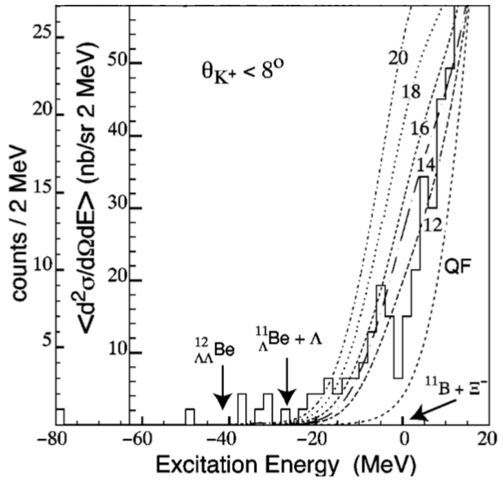
$V_{0\Xi}$: Strength of the potential

$W_{0\Xi}$: Absorption processes ($\Xi^- p \to \Lambda\Lambda$, $\Xi^- p \to \Xi^0 n$)

BNL-E885

$^{12}\mathrm{C}(K^-, K^+)$ reaction at 1.8 GeV/c

- (DWIA) $V_{0\Xi} \sim -14$ MeV by neglecting the $W_{0\Xi}$
- (SCDW) $V_{0\Xi} \sim 0$ with Γ/2=2 MeV



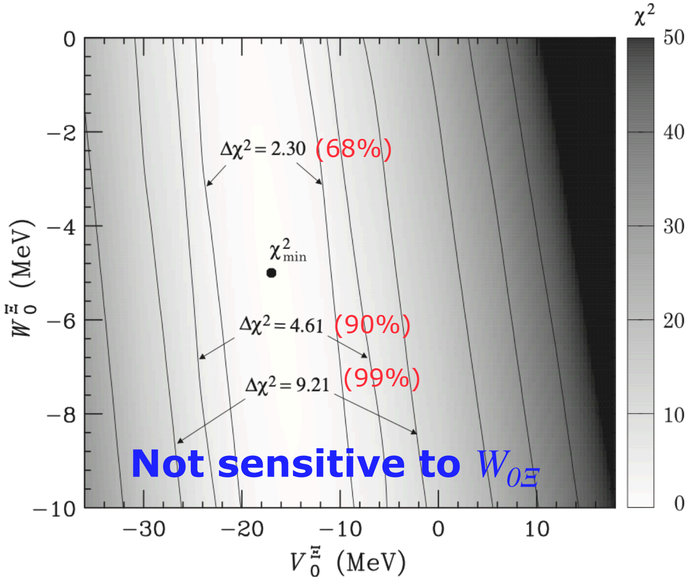
*P. Khaustov et al., PRC 61 (2000) 054603

*M. Kohno and S. Hashimoto, Prog. Theor. **123**, (2010).

BNL-E906

$^{9}\mathrm{Be}(K^-, K^+)$ reaction at 1.8 GeV/c

$$U_{\Xi}(r) = (V_{0\Xi} + iW_{0\Xi})/[1 + \exp(r - R)/a]$$



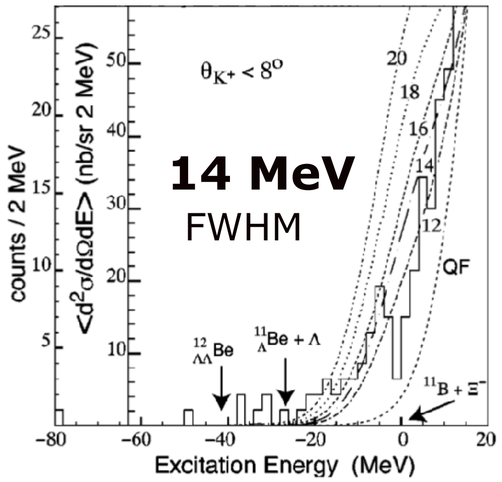
*T.Harada and Y. Hirabayashi, Phys. Rev. C **103**, 024605 (2001)

Experiments for Ξ^--nucleus Potential for $^{12}\mathrm{C}(K^-, K^+)$ Reaction

- Relative experiments with $^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$ spectroscopy

BNL-E885

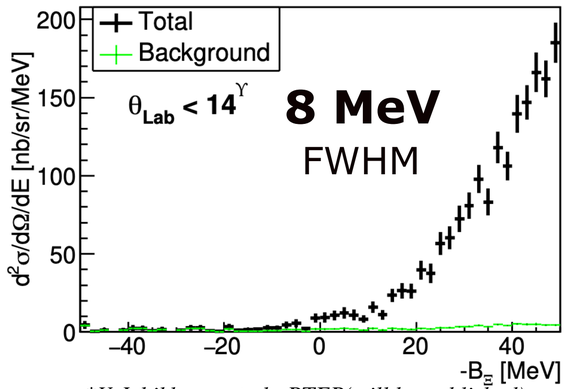
$V_{0\Xi} \sim -14$ MeV



*P. Khaustov et al., PRC 61 (2000) 054603

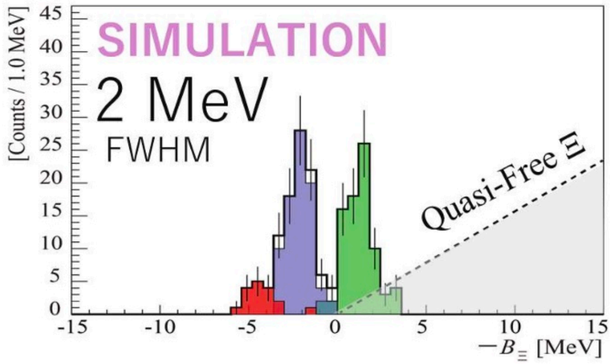
J-PARC E05/E70(in progress) Experiments

- $^{12}\mathrm{C}(K^-, K^+)$ spectrum with wide range



*Y. Ichikkawa et al., PTEP(will be published)

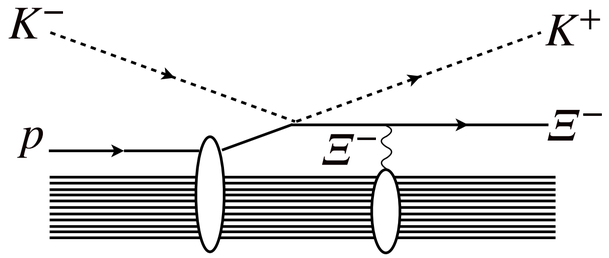
- High-resolution **2 MeV** measurement



*T. Gogami et al., WPJ Web Conf. 271 (2022) 11002

c.f) E42 MM resolution: **24 MeV** (FWHM)

- E42 is sensitive to determine $W_{0\Xi}$ by decomposing the inclusive spectrum into $\Xi^- p \to \Lambda\Lambda$ conversion and others by HypTPC.



J-PARC E42 Detector at the J-PARC K1.8 beam line

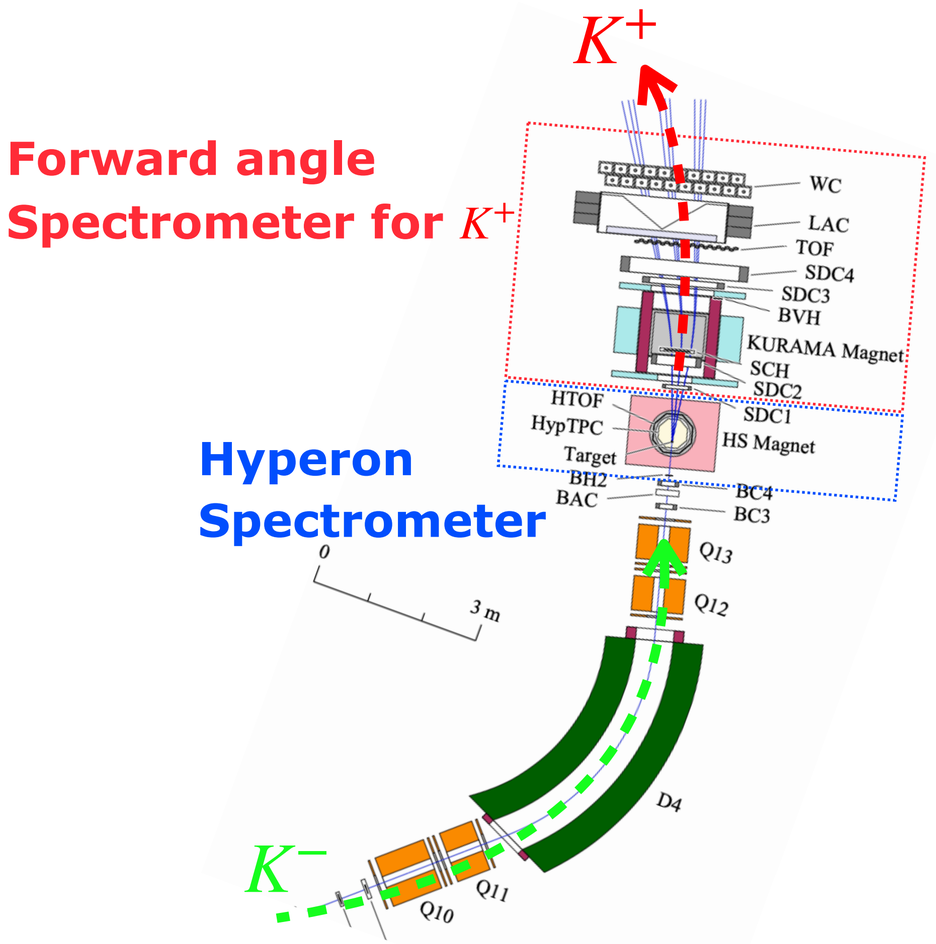
- J-PARC E42 detector consists with two detector systems.
- Both were utilized simultaneously for different analysis.

Forward angle Spectrometer for K^+

- Particle identification for K^+ selection
- Missing-mass spectroscopy for (K^-, K^+) reactions

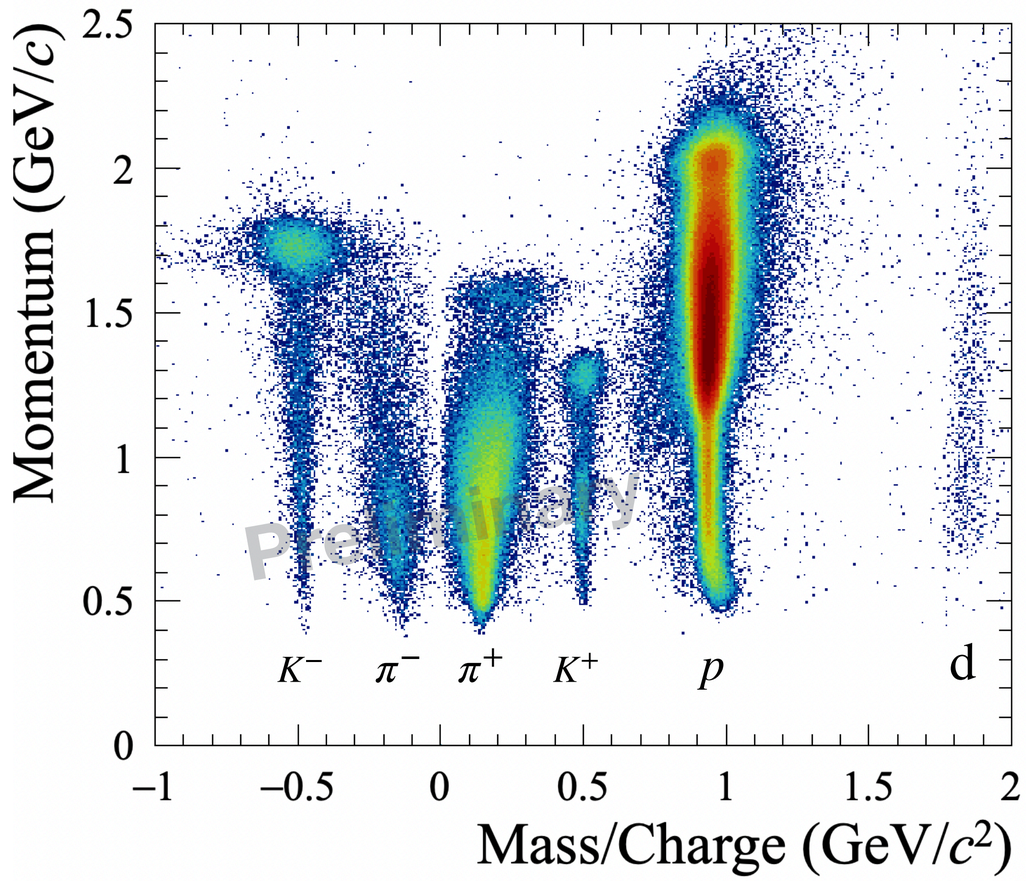
Hyperon Spectrometer

- Charged particle reconstruction by Time-projection chamber called HypTPC
- Reconstruction of Λ and Ξ^- and its sequential decays.



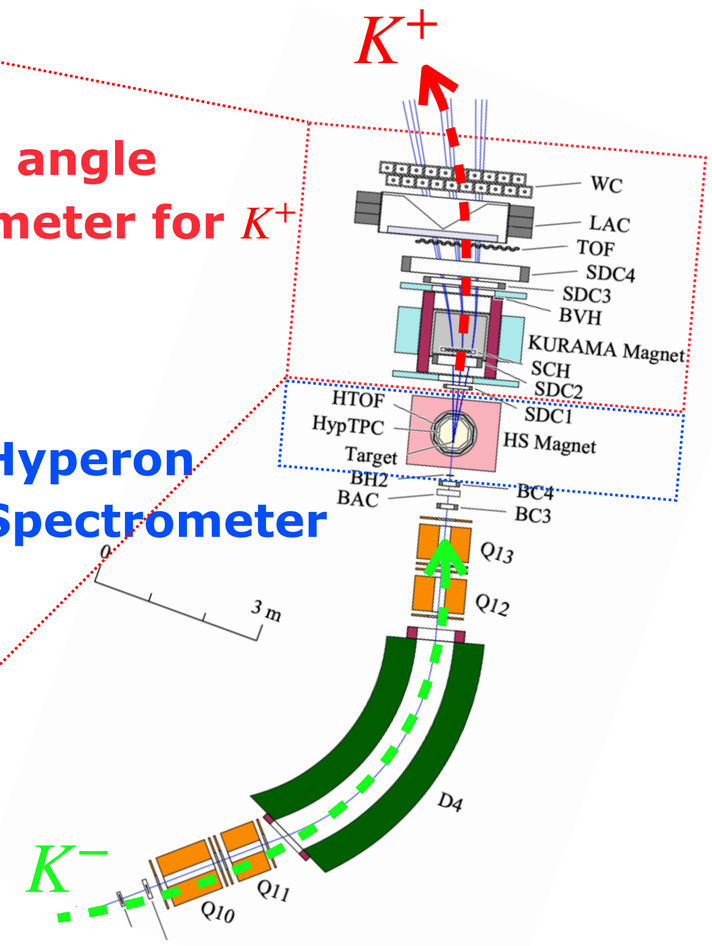
J-PARC E42 Detector at the J-PARC K1.8 beam line

Scattered particles at forward angles



Forward angle Spectrometer for K^+

Hyperon Spectrometer



J-PARC E42 Detector: Hyperon Spectrometer

HypTPC (Main tracking device for hadron experiments)

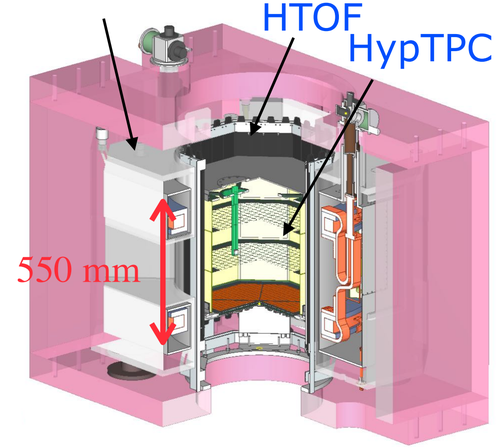
- **Visualize trajectories** for charged decays in 3D
- A target is embedded inside for **large acceptance**.

HTOF (Multiplicity trigger detector)

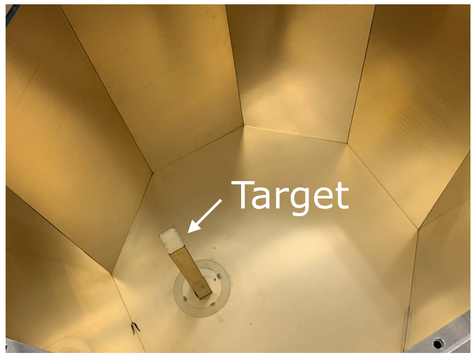
- TOF counter surrounding TPC

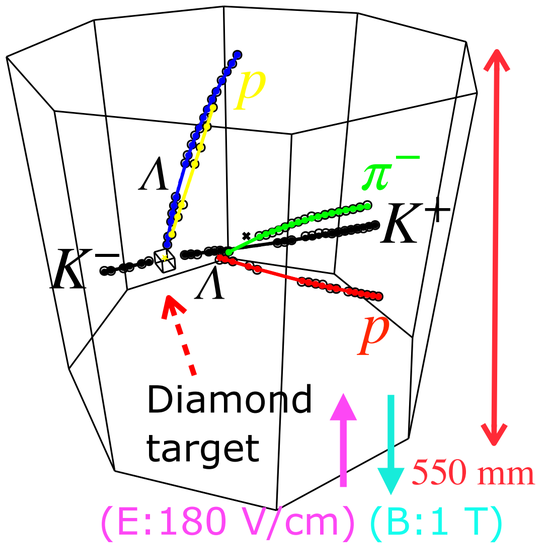
Reconstruction of Ξ^-/Λ and others

SC Magnet(1 T)

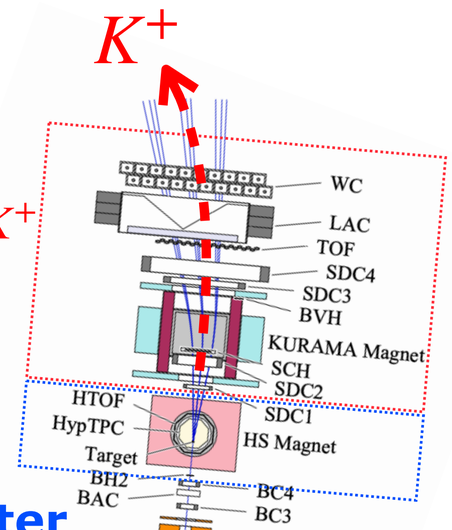


Field cage
&Target holder

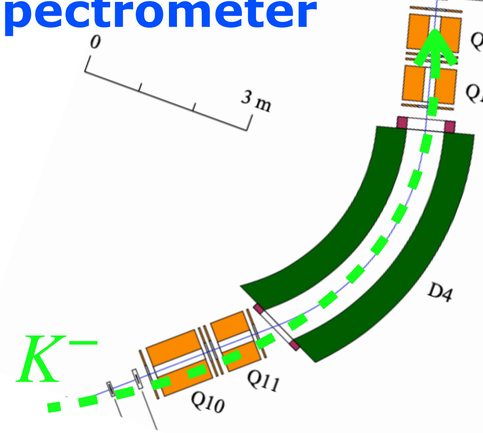




Forward angle Spectrometer for K^+



Hyperon Spectrometer



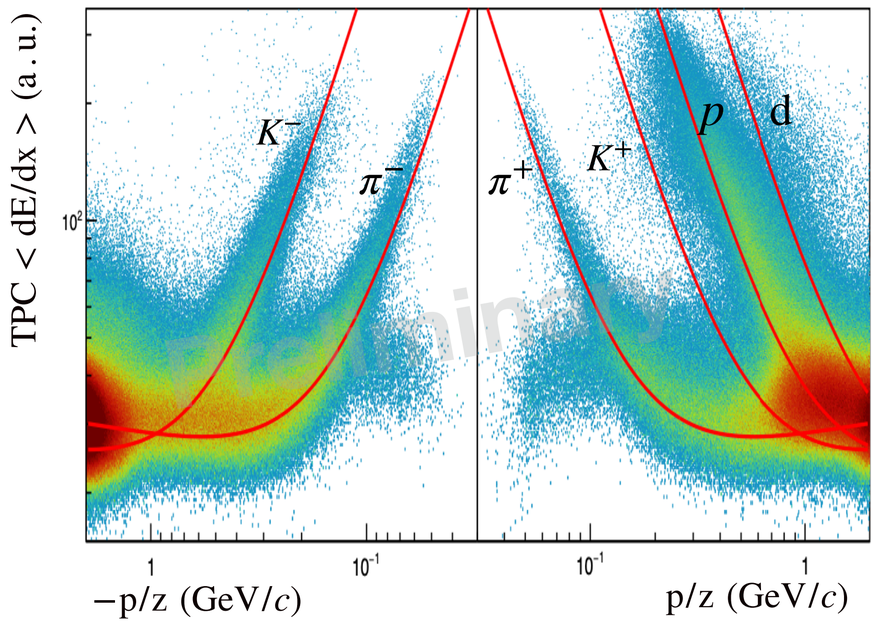
Particle Identification by Hyperon Spectrometer

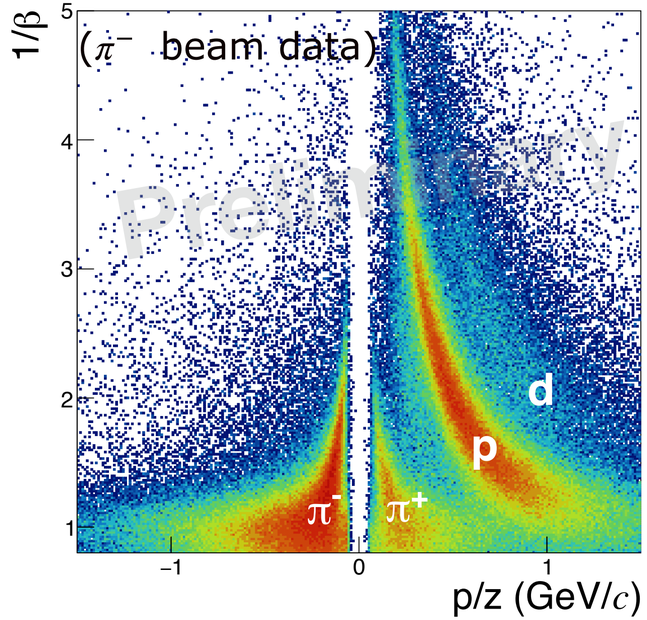
HypTPC dE/dx

- $< dE/dx >_{20\%\ truncated}\ vs\ p/z$ for reconstructed tracks of $^{12}C(K^-, K^+)$ reactions
- $\sigma_{<dE/dx>} / < dE/dx >$ ~ 20% for the range 0.40 < p_T < 0.45 GeV/c

HTOF Time-of-flight

- Flight length about 200 ~ 500 mm, σ_t ~ 120 ps for π^-



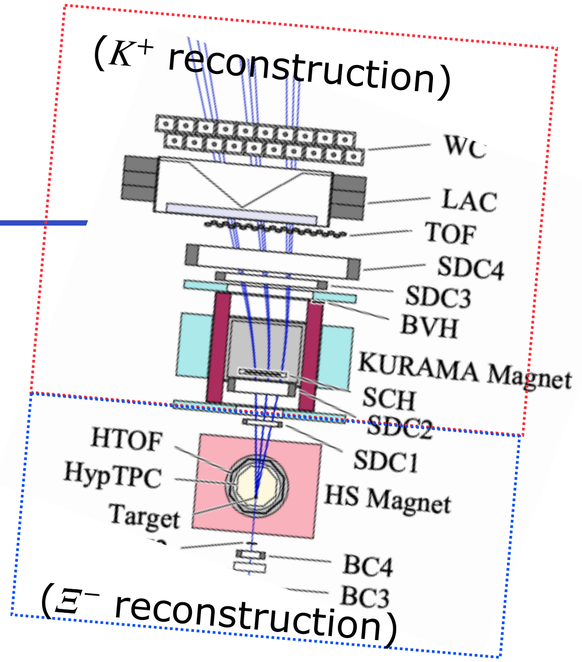


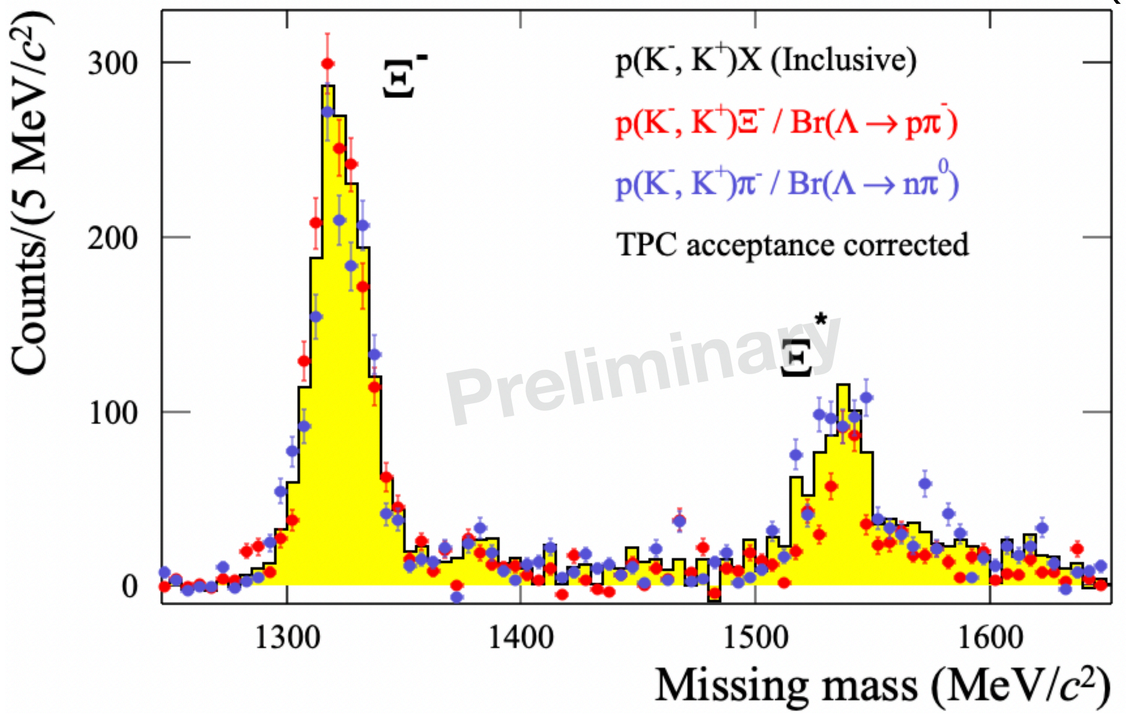
Missing-Mass Spectrum for $p(K^-, K^+)X$ reactions

The missing-mass spectrum for $p(K^-, K^+)X$ reactions is reproduced with Ξ^- reconstructed events for

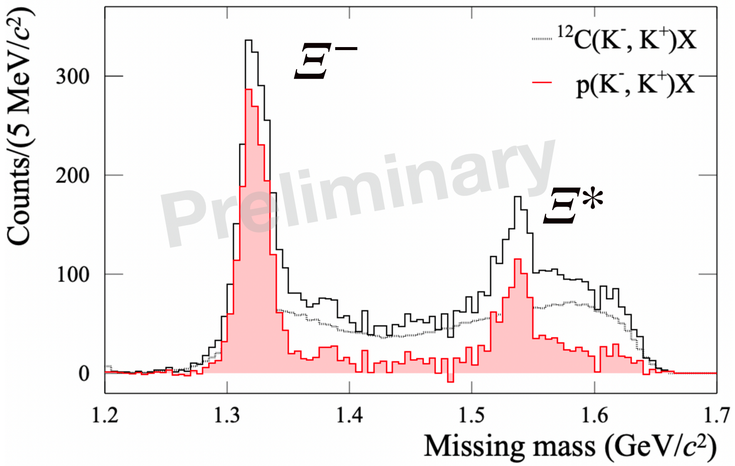
1. visible Λ decays 2. invisible Λ decays in the TPC.

The reconstruction efficiencies for Ξ^- decays were obtained by simulation (~70% for Ξ^-, ~92% for Λ)





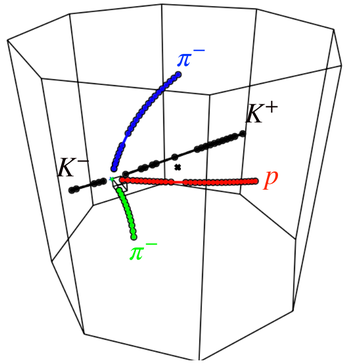
^{12}C contribution subtracted from the spectrum with a CH_2 target



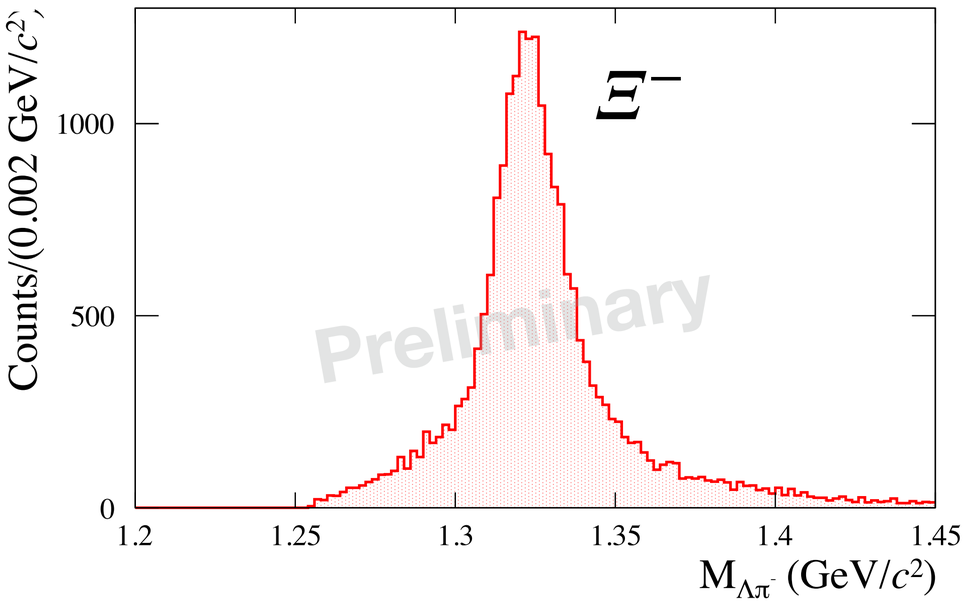
Ξ^- Production in the $^{12}C(K^-, K^+)$ reaction

- $\Xi^- \to \Lambda\pi^-$ and its visible decays are reconstructed by HypTPC.
- Ξ^- escaping probability provides information on ΞN Interaction

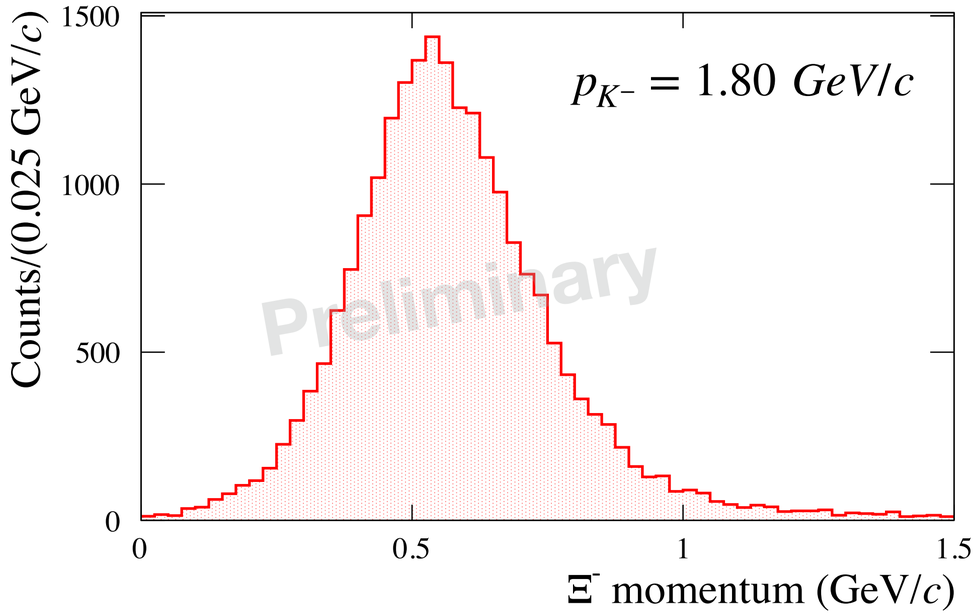
$\Xi^- \to \Lambda\pi^-, \Lambda \to p\pi^-$



Invariant Mass



Ξ^- momentum

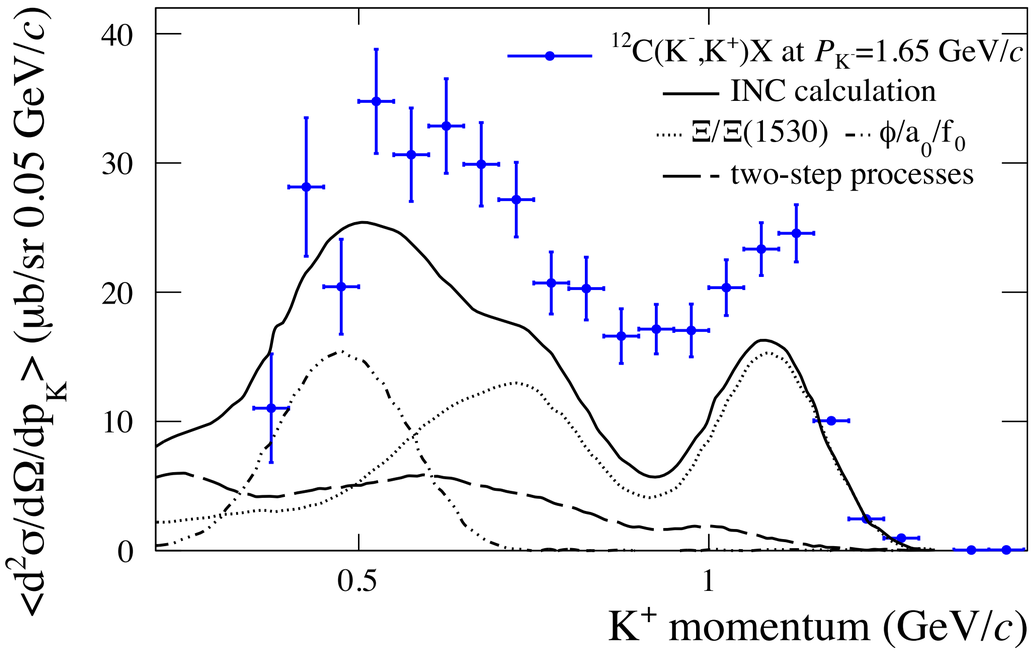


Individual Elementary Processes in $^{12}C(K^-, K^+)X$

- Both one-step and two-step processes may contribute to the $^{12}\mathbf{C}(K^-, K^+)X$ reactions.
- Past experimental data(KEK E176) with Intranuclear cascade model calculation

*T. Iijima et al., Nucl. Phys. A 546, 588 (1992)

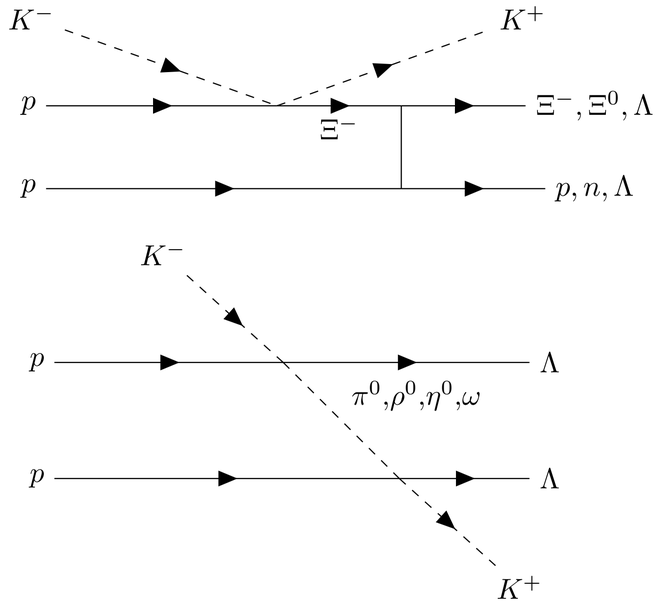
*Y. Nara, A. Ohnishi, T. Harada, A. Engel, Nucl. Phys. A 614, 433 (1997)



- One step processes

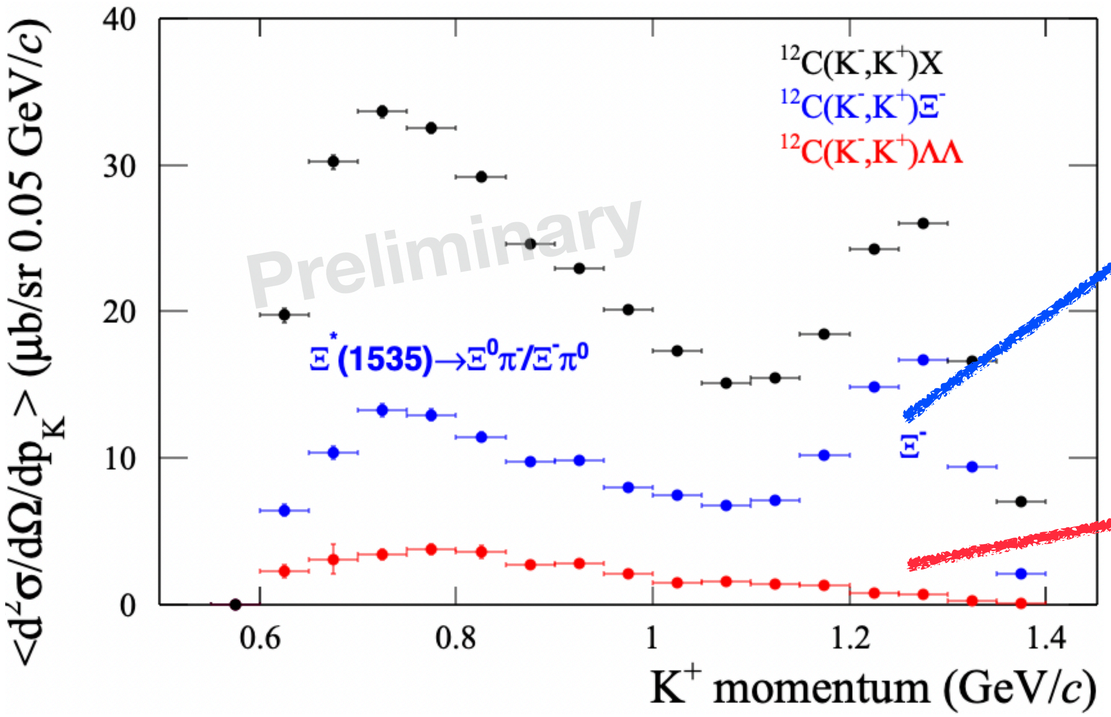
$$K^-p \to K^+\Xi^-$$
$$K^-p \to K^+\Xi(1535)^-$$
$$K^-p \to \begin{pmatrix} \phi \\ a_0 \\ f_0 \end{pmatrix}\Lambda$$

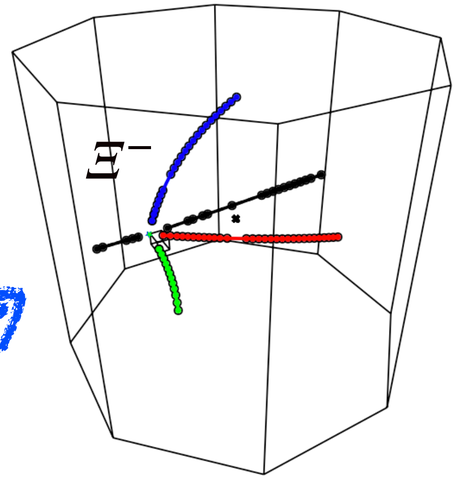
- Two-step processes



Double differential cross-sections for exclusive processes in $^{12}\mathrm{C}(K^-, K^+)X$ reactions

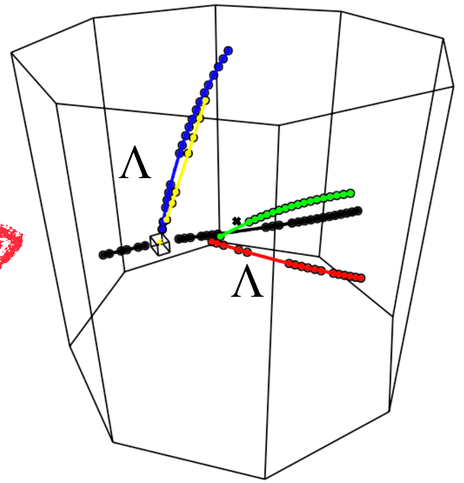
- Inclusive spectrum for $^{12}\mathrm{C}(K^-, K^+)X$reaction is decomposed into Ξ^- escaping and $\Xi^- p \to \Lambda\Lambda$ conversion spectra.
- Crucial information for determination of ΞN **potential** (Sensitive to determine conversion strength)





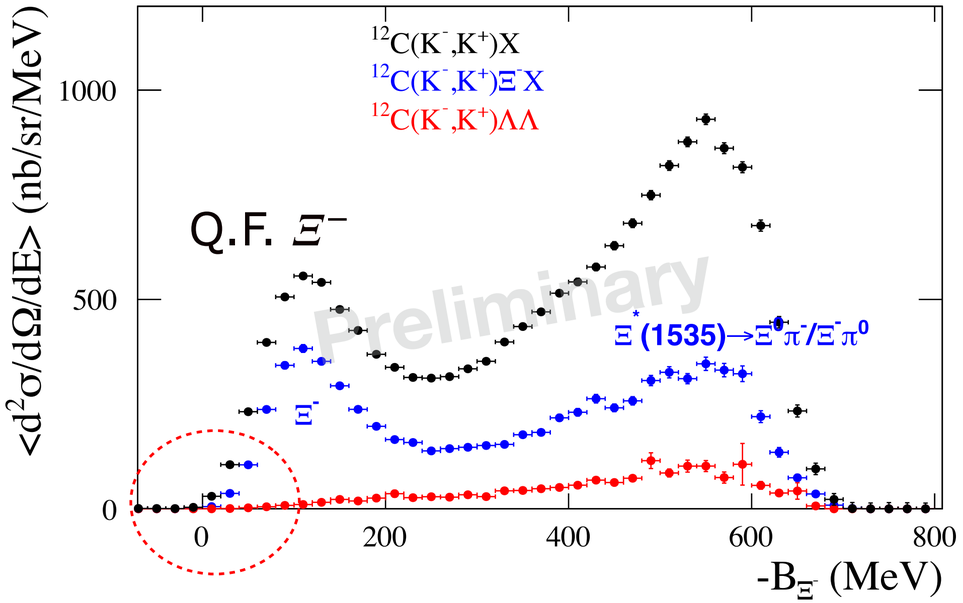
Ξ$^-$ escaping

$\Xi^- p \to \Lambda\Lambda$ conversion

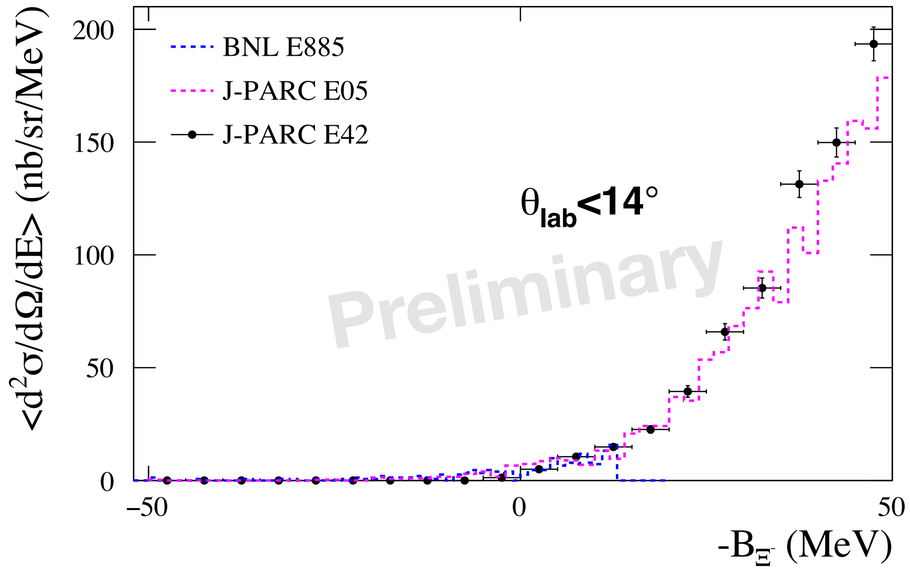


Binding Energy Spectrum for $^{12}\mathrm{C}(K^-, K^+)X$ reaction

$B_{\Xi^-} = \mathrm{M_X} - \mathrm{M}(\Xi^-) - \mathrm{M}(^{11}\mathrm{B})$ where $\mathrm{M_X}$:$^{12}\mathrm{C}(K^-, K^+)\mathrm{X}$

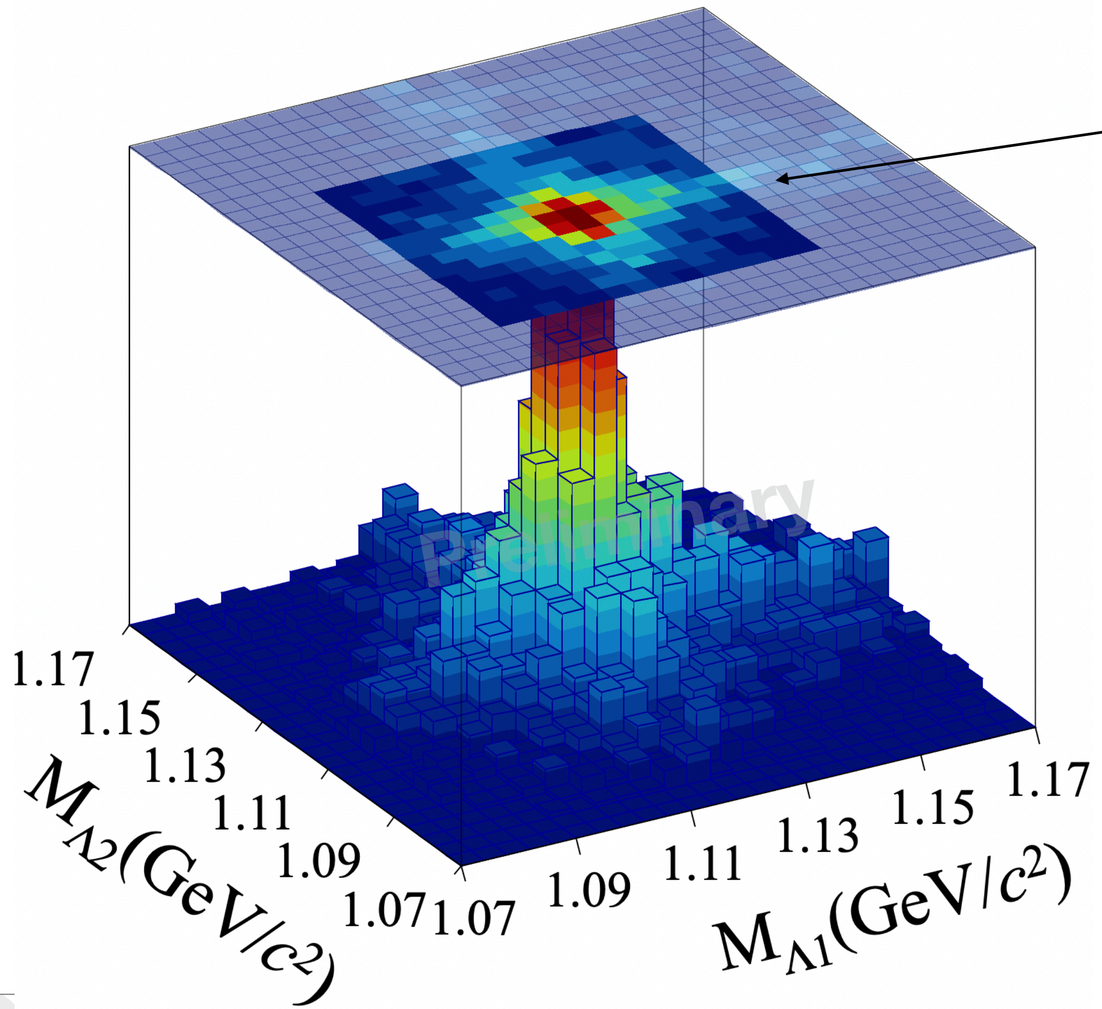


*P. Khaustov et al., PRC 61 (2000) 054603
*Y. Ichikkawa et al., PTEP(will be published)



- E42 data can provide information on **individual processes** including Ξ^- and $\Lambda\Lambda$ emission for potential study and we are also interested in $\Xi^- p$ system.
- **The escaping probability** of quasi-free Ξ^- in the $^{12}\mathrm{C}$ nucleus is approximately 2/3.
- Measurement of **sequential decays of hypernuclei** involving two pions is also our interest.

Reconstructed ΛΛ Production Events



~3000 events with ΛΛ pairs
in the signal box

- Two orders of magnitude more $\Lambda\Lambda$ events then ever in past experiments
- Blind analysis for H-dibaryon search is now underway.

Summary

- **J-PARC E42 searches for the H-dibaryon via $^{12}\mathrm{C}(K^-, K^+)$ reaction.**
  We collected approximately 0.3M (K^-, K^+) reaction events and measured all charged decays using HypTPC.

- We report preliminary J-PARC E42 results on **differential cross-section measurement for $^{12}\mathrm{C}(K^-, K^+)X$ reactions.**

- This result can provide crucial information for determining **the imaginary term in $\Xi^- N$ potential** which corresponds to **the strength of assumption processes of Ξ^- in $^{12}\mathrm{C}$ nucleus.**

J-PARC E42 byproducts

(K^-, K^+) reaction at 1.8 GeV/c

- Differential Cross-section Measurement for $^{12}C(K^-, K^+)X$ Reactions
  (Ξ^--nucleus potential study)

where, $U_{\Xi^-} = [V_0^{\Xi} + iW_0{}^{\Xi} g(E)]f(r)$

$V_{0\Xi}$: Strength of the potential

$W_{0\Xi}$: Absorption processes

$(\Xi^- p \to \Lambda\Lambda,\ \Xi^- p \to \Xi^0 n)$

E42 is sensitive to determine $W_{0\Xi}$ by decomposing the inclusive spectrum into $\Xi^- p \to \Lambda\Lambda$ conversion and other processes by HypTPC.

- Differential Cross-section Measurement of $K^- p \to K^+ \Xi(1535)^-$
- $\Xi^-/\Xi(1535)^-$ Polarization Measurement

(K^-, p) reaction at 1.8 GeV/c

- Cross-section Measurement of $\mathbf{p}(K^-, p)K^*(892)X$ and $^{\mathbf{12}}\mathbf{C}(K^-, p)K^*(892)X$
- Kaonic Nucleus Search by $^{\mathbf{12}}\mathbf{C}(K^-, p)X$

Past experimental data for $\Xi^- p \to \Lambda\Lambda$ cross-section

Ξ^--nucleus Potential

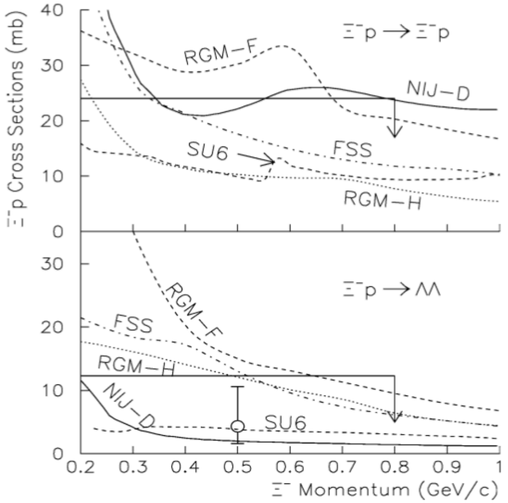
$$U_{\Xi^-} = [V_0^{\Xi} + iW_0{}^{\Xi} g(E)] f(r)$$

where,

$V_{0\Xi}$: Strength of the potential

$W_{0\Xi}$: Absorption processes ($\Xi^- p \to \Lambda\Lambda$, $\Xi^- p \to \Xi^0 n$)

- Past experimental data on low-energy $\Xi^- p$ elastic, $\Xi^- p \to \Lambda\Lambda$ cross-section (KEK E224)



The total cross-section of $\Xi^- p \to \Lambda\Lambda$ and the width of Ξ^- state in nuclear matter

$$\sigma_{\Xi^- p \to \Lambda\Lambda} = 4.3^{+6.3}_{-2.7}\ \text{mb},\ \Gamma_{\Xi^-} \sim 3\ \text{MeV}$$

*J.K. Ahn et al. / Physics Letters B 633 (2006) 214–218

- Recent emulsion experiments($\Xi^- -{}^{14}\mathrm{N}$ bound state):

J-PARC E07(IRRAWADDY, IBUKI), KEK E373 (KISO)

-> Attractive Ξ^- nucleus potential with a weak ΞN-ΛΛ coupling

*M. Yoshimoto, Prog. Theor. Exp. Phys. **2021**, 073D02.
*S. H. Hayakawa et al./ Phys. Rev. Lett. 126, 062501 (2021).