An H-dibaryon search experiment at J-PARC and its various byproducts

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for the J-PARC E42 collaboration

NSTAR2024

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- Search for H-dibaryon
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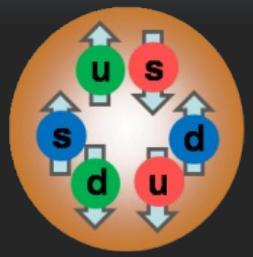
  - Measurement of Ξ-nucleus optical potential via $^{12}\mathrm{C}(K^-, K^+)$
  - Polarization measurement of Ξ and $\Xi^*(1535)$ via $\mathrm{p}(K^-, K^+)\Xi/\Xi^*$
  - Study of ChSB effect by measurement of $K^*(892)$ vector mass via $^{12}\mathrm{C}(K^-, p)$

Search for H-dibaryon

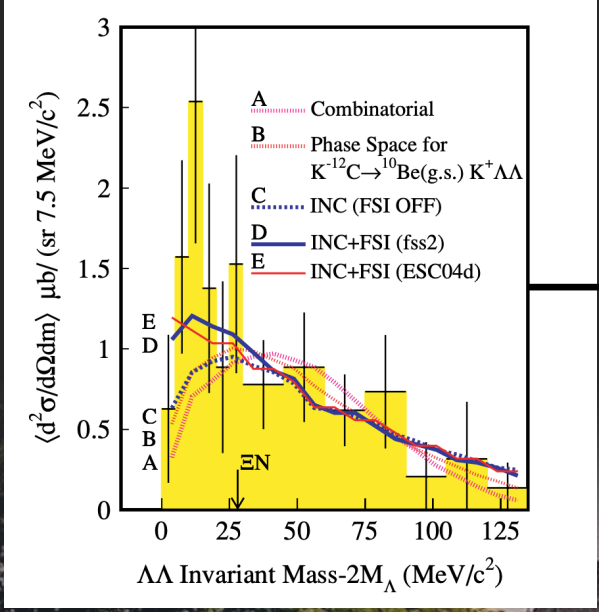


- **H-dibaryon** : exotic hadron, six quark state of uuddss (I=0, J=0)
- Bound or resonance? Mass close to $\Lambda\,\Lambda$ or ΞN threshold?
  - Very meaningful because this state is deeply related to $\Lambda\,\Lambda - \Sigma\Sigma - \Xi N$ coupling channel
  - Lattice QCD calculation → near ΞN threshold
- History of H-dibaryon search

KEK-PS E522

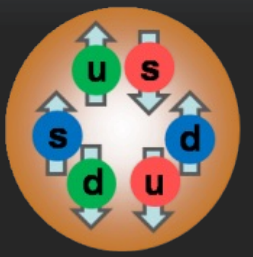
statistics & resolution not enough

C. J. Yoon *et al.* Phys. Rev. C **75**, 022201(2007)



1977	Deeply-bound di-hyperon predicted by R. Jaffe
1980-2000	No evidence for the deeply-bound H from KEK, BNL, and CERN experimental efforts by more than 80 MeV
2001	Mass constraint from observation of ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ (E373)
1998,2007	Enhanced $\Lambda\Lambda$ production near threshold was reported from E224 and E522 at KEK-PS.
2011	LQCD calculations predict the H-dibaryon near $m_{\Lambda\Lambda}$
2013-2015	No evidence for $H \to \Lambda p \pi^-$ and $H \to \Lambda\Lambda$ in high-energy e^+e^-, pp and AA experiments
2021	LQCD calculations point to the mass the H-dibaryon very close to ΞN threshold ($m_\pi \approx 146$ MeV)
2021	J-PARC E42 has successfully completed with HypTPC.

Search for H-dibaryon



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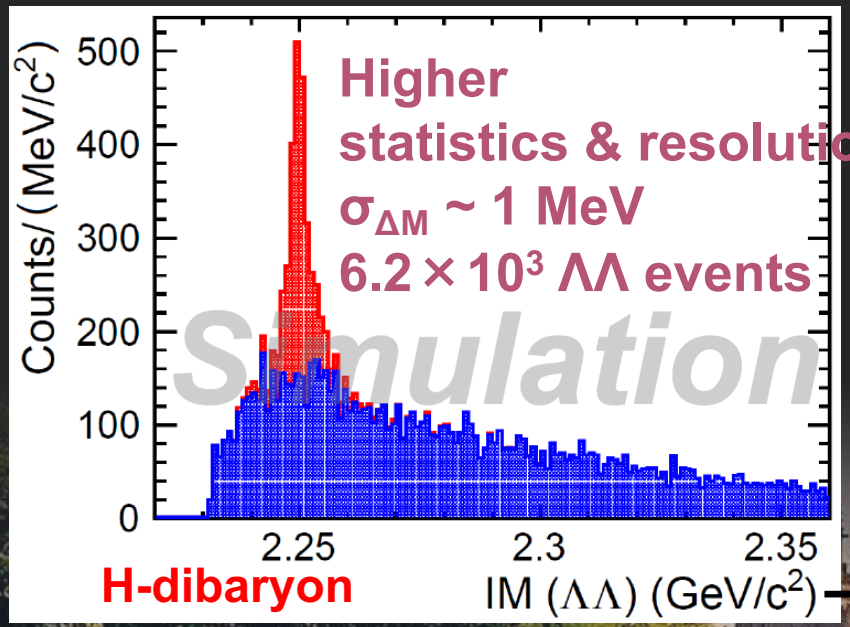

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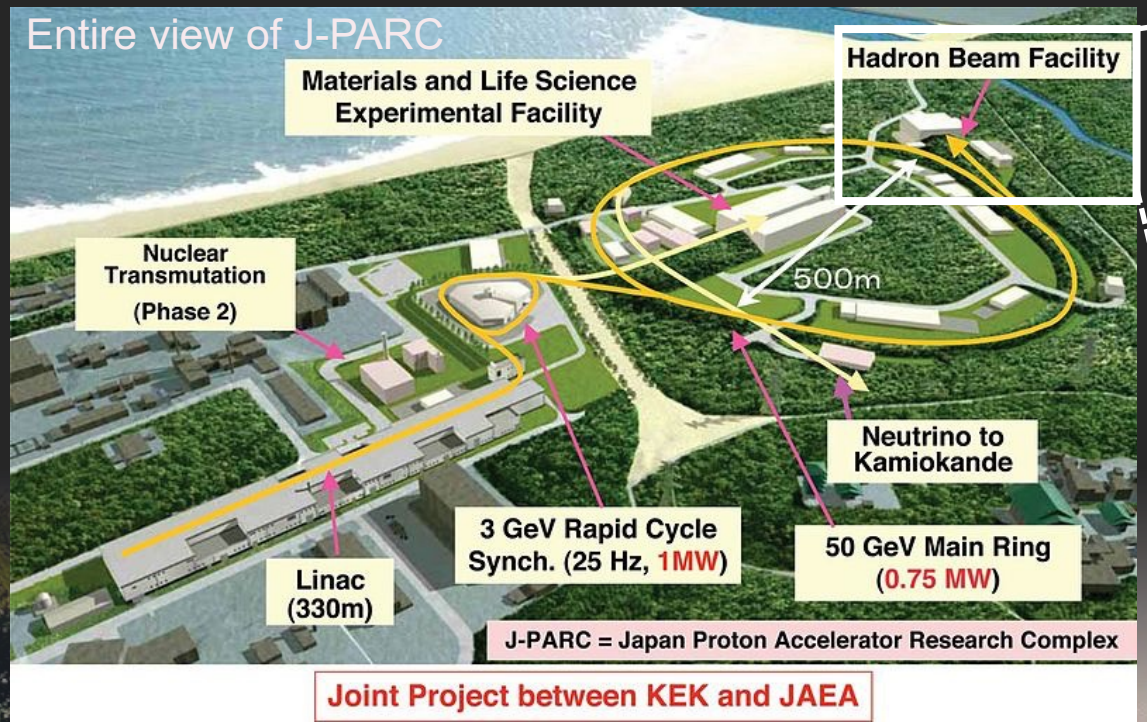
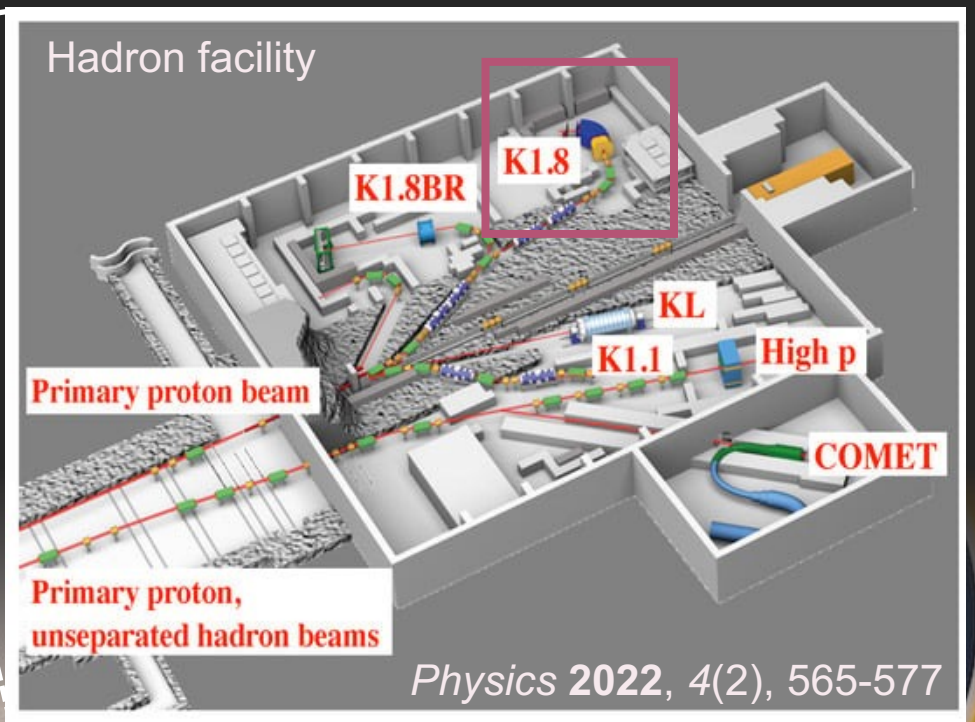
2021	**J-PARC E42 has successfully completed with HypTPC.**

J-PARC E42 experiment

- **J-PARC** (Japan Proton Accelerator Research Complex)
  high energy and high intensity proton beam is available
- Hadron hall
  We can use a variety of secondary beams such as kaon, pion, and so on.



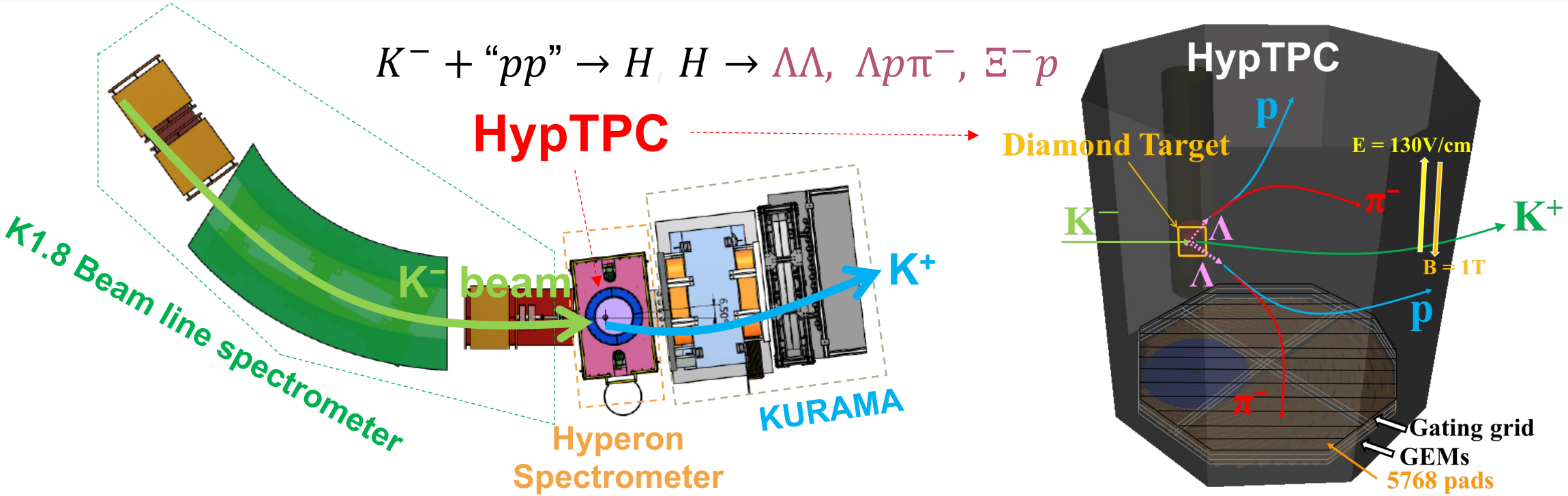


J-PARC E42 experiment

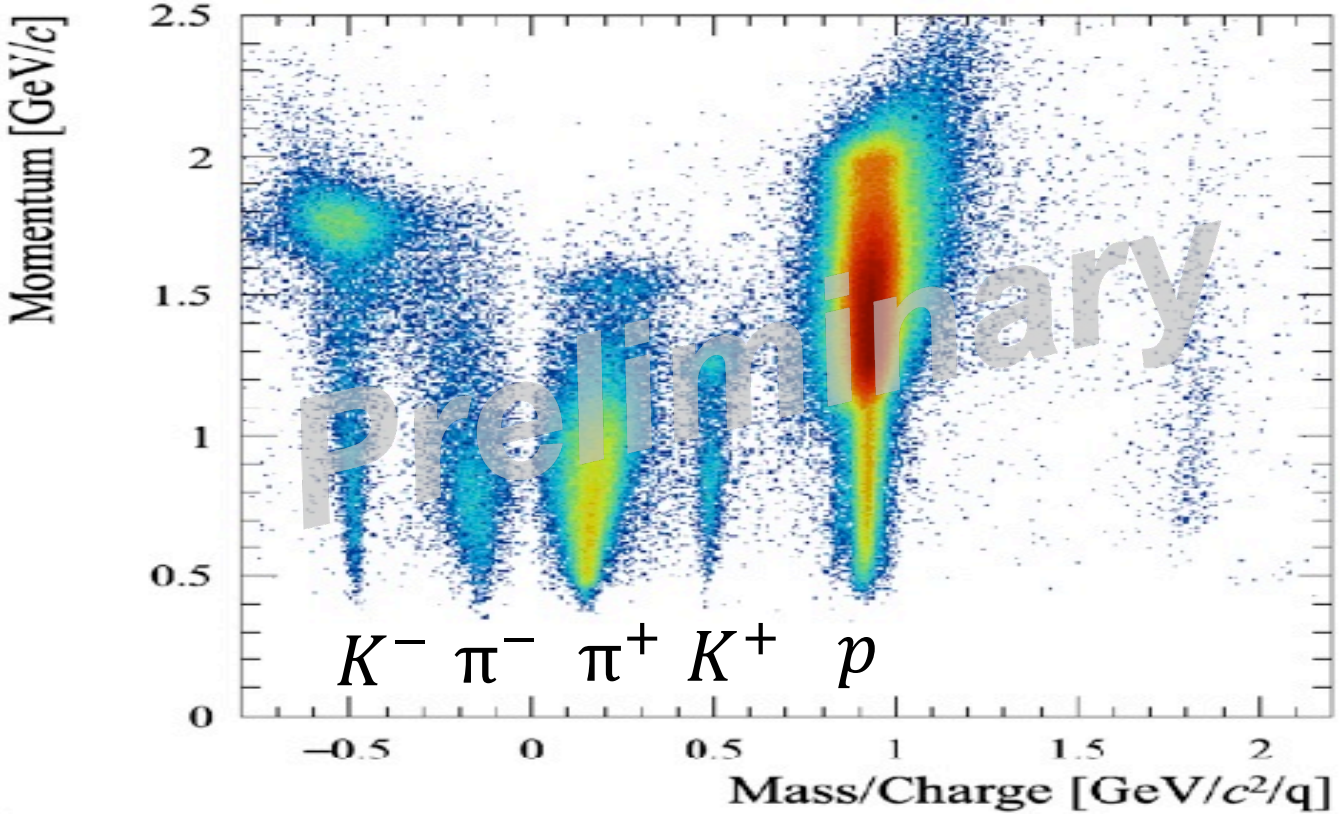
- Invariant mass spectroscopy of H-dibaryon using **HypTPC** (J-PARC E42)

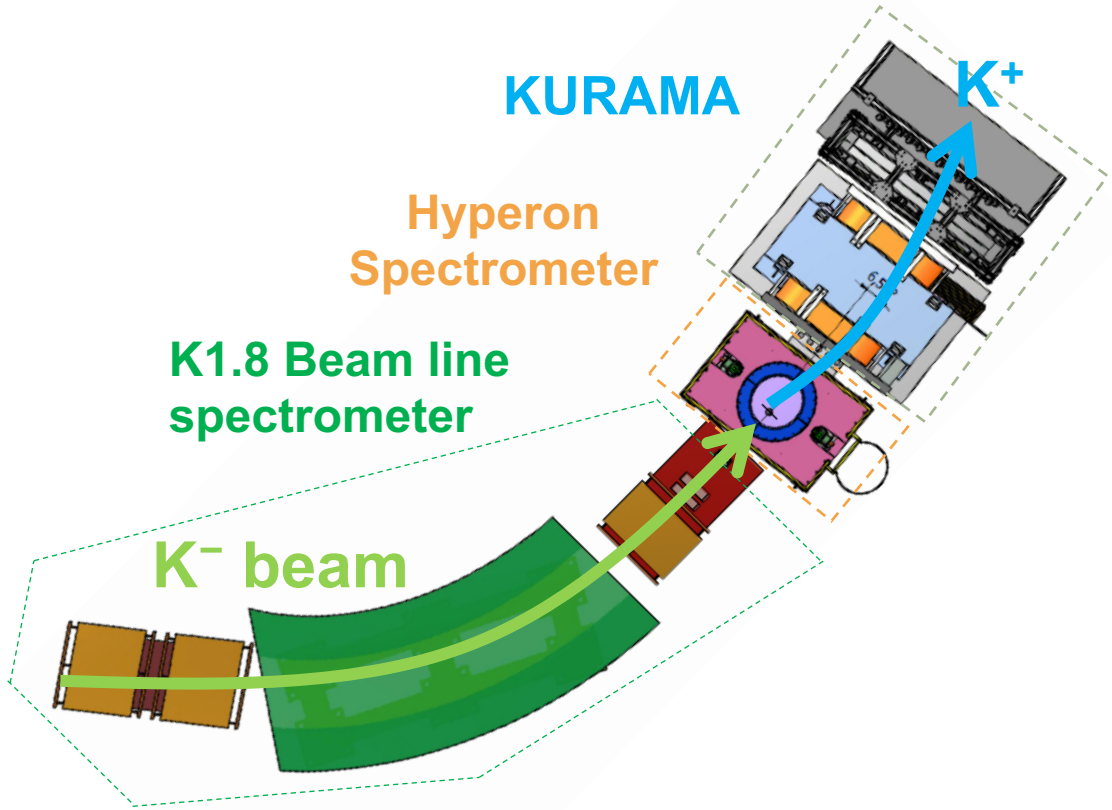
  Completed in 2021

  -1.8 GeV/c Kaon beam on a diamond target

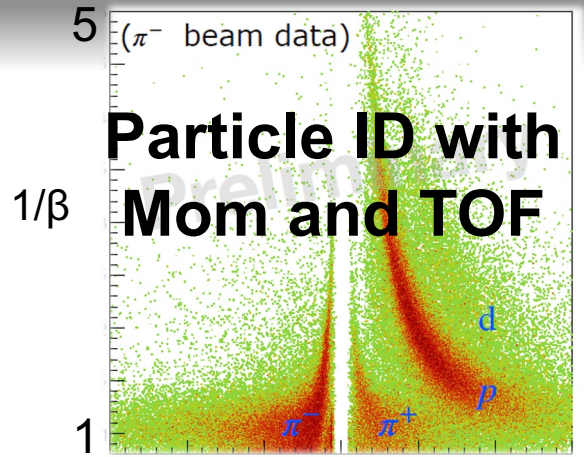


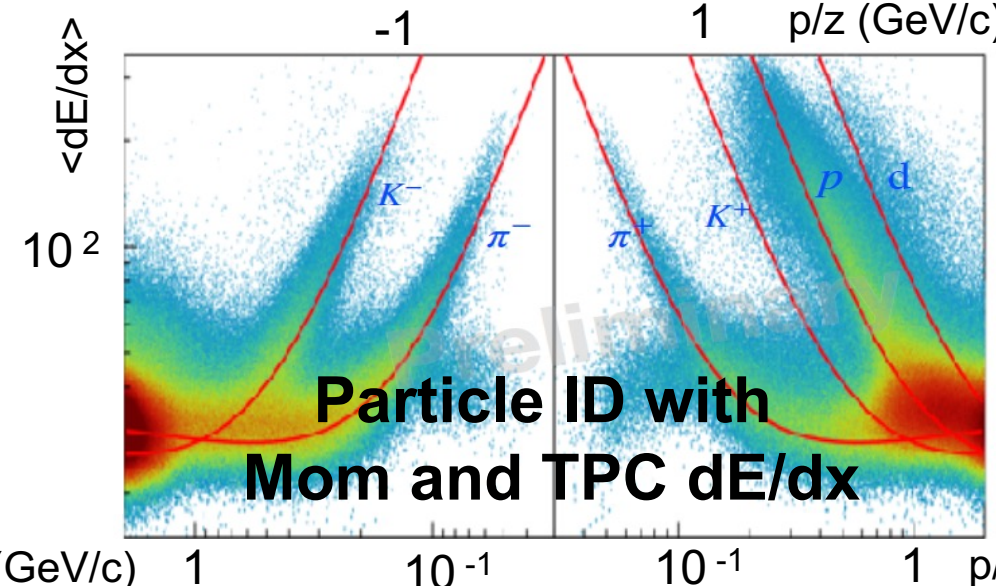
Analysis of KURAMA spectrometer for the forward scattered particles

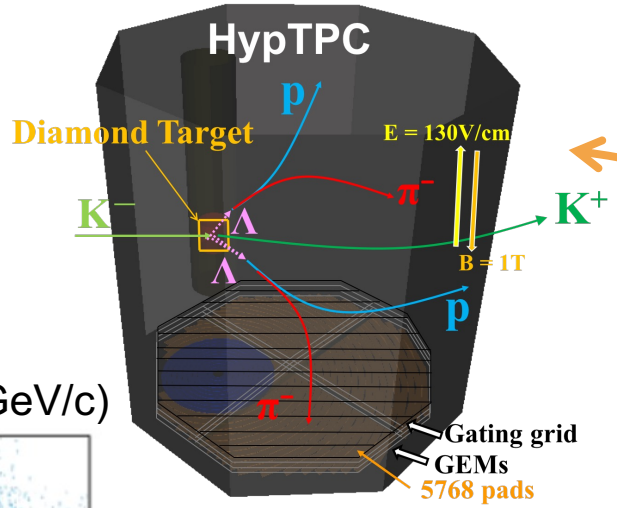


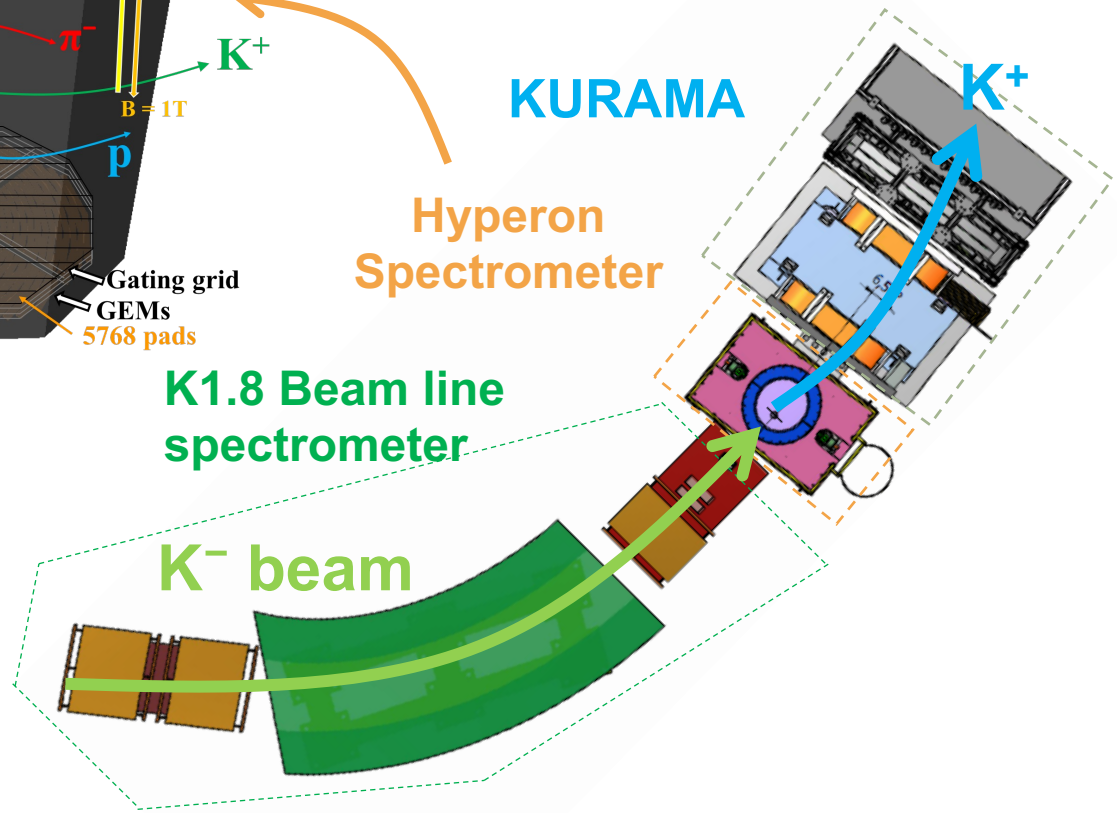


Analysis of Hyperon Spectrometer (HypTPC) for decay particles



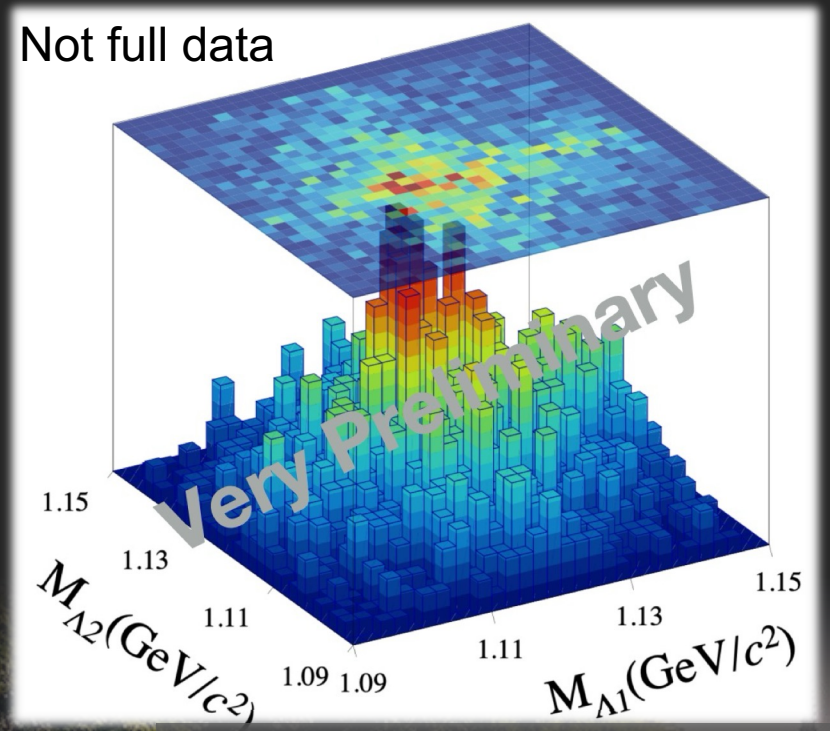






ΛΛ reconstruction

3000 ΛΛ events are reconstructed (not full data)



Summary of past experiments

	KEK E224	KEK E522
Beam K^-	$p_{(K^-)}$ = 1.65 GeV/c	$p_{(K^-)}$ = 1.66 GeV/c
$p_{(K^+)}$ [GeV/c]	0.95<$p_{(K^+)}$ <1.3	0.9<$p_{(K^+)}$ <1.3
dσ/dΩ（ΛΛ）	7.6 μb/sr	12.8 μb/sr
ΛΛ yield	35 events	68 events

Comparison with expected yield

$p_{(K^+)}$ [GeV/c]	**0.95<$p_{(K^+)}$ <1.3**		**0.5 < $p_{(K^+)}$**
Assumed dσ/dΩ(ΛΛ)	7.6 μb/sr	12.8 μb/sr	
Expected ΛΛ	337 events	570 events	
Expected ΛΛ yield	520 events	880 events	
Measured ΛΛ yield	1,390 events		3,030 events

More than expected! We will open H-dibaryon box soon!

HypTPC enables investigation in many other topics as well

- We are currently working on the following topics using E42 data;
  1. Kaonic nucleus search via exclusive $^{12}\mathrm{C}(K^-, p)$ reaction
  2. Measurement of Ξ-nucleus optical potential via $^{12}\mathrm{C}(K^-, K^+)$
  3. Polarization measurement of Ξ and $\Xi^*(1535)$ via $\mathrm{p}(K^-, K^+)\Xi/\Xi^*$
  4. Study of ChSB effect by measurement of $K^*(892)$ vector mass via $^{12}\mathrm{C}(K^-, p)$

Hopefully, there may be many other byproducts!

Byproduct1.

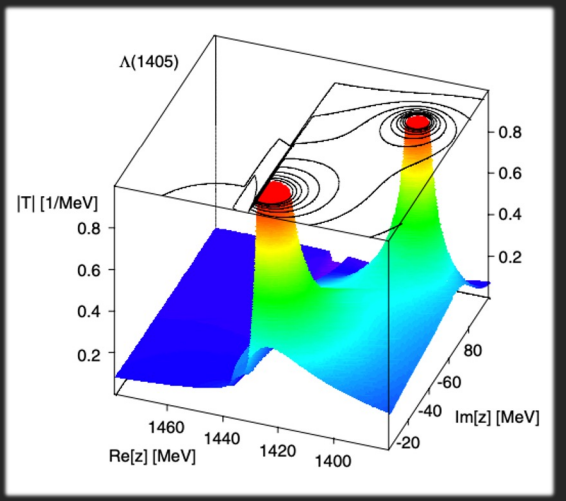
Kaonic nucleus search

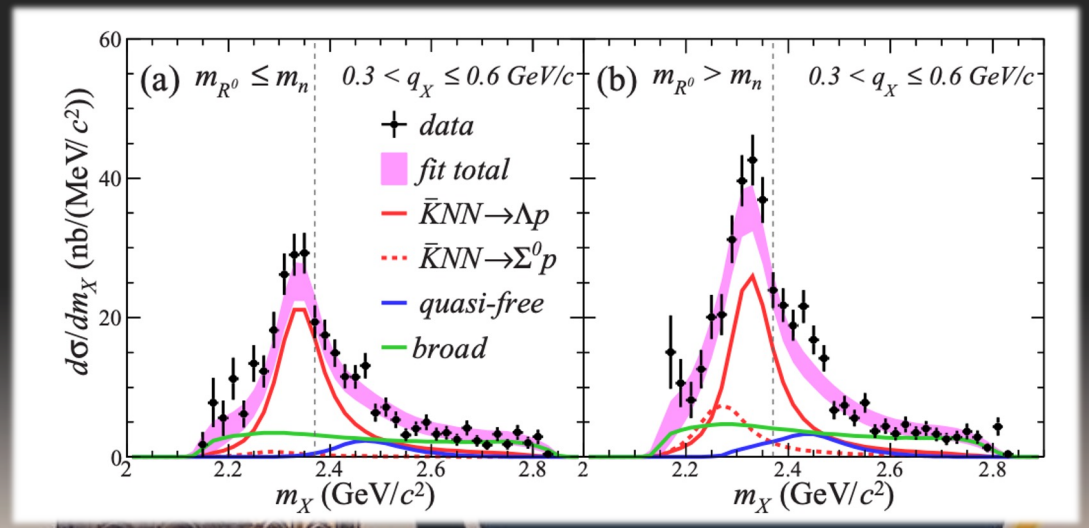
- $\bar{K}N$ interaction & bound system -

- $\bar{K}N$ (I=0) attractive interaction results in $\Lambda^*(1405)$? [1]

- $\bar{K}NN$ state search (J-PARC E15) [2]
  - Clear bump structure in I.M. *via* $^3\mathrm{He}(K^-, \Lambda p)n$
  - Lightest kaonic nucleus
  - $B_K = 42 \pm 3\ ^{+3}_{-4}$ MeV / $\Gamma_K = 100 \pm 7\ ^{+19}_{-9}$ MeV
  - Due to $\bar{K}N$ and Λ^*N attraction?

[1] T. Hyodo, D. Jido
Prog. Part. Nucl. Phys., **67**,
021D01 (2015)





[2] T. Yamaga *et al.*
Phys. Rev. C **102**,
044002 (2020)

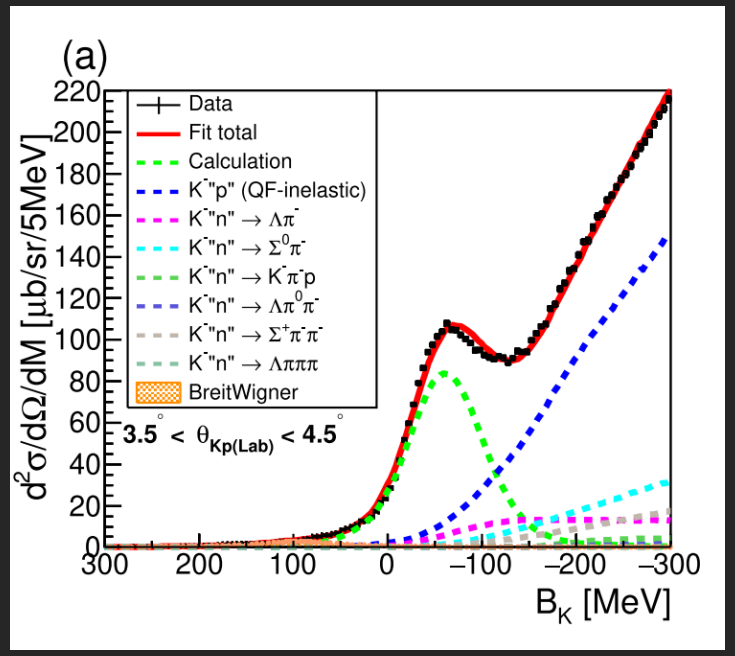
Byproduct1.

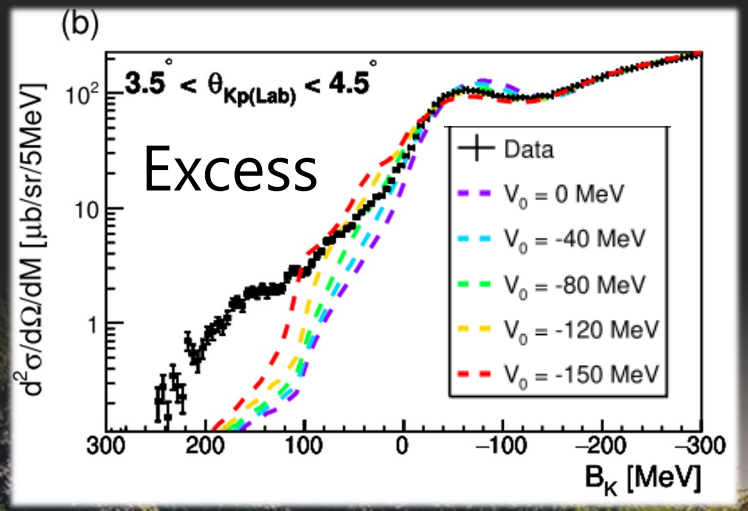
Kaonic nucleus search

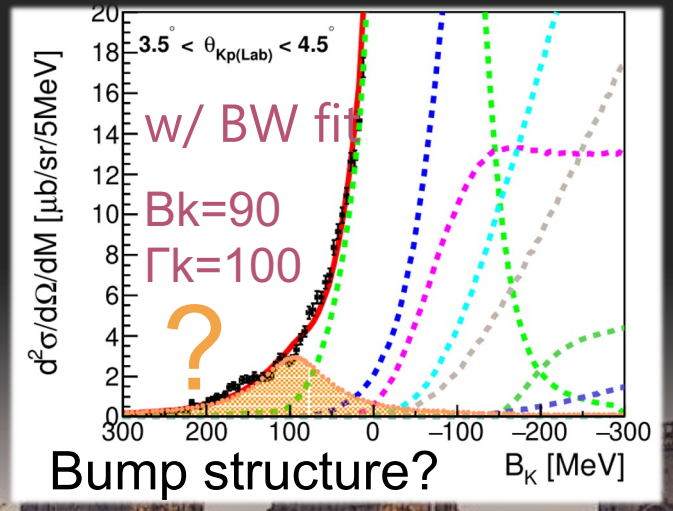
- $\bar{K}N$ interaction & bound system -

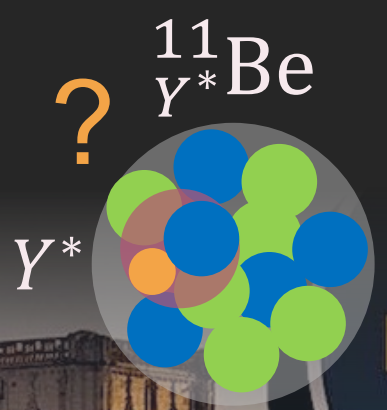
- $^{12}\mathrm{C}(K^-, p)$ missing mass
  - Optical potential between K^- and the core nucleus
    - $(V_0, W_0) = (-80, -40)$ [MeV] [3]
      (V_0, W_0: real/imaginary part)
  - Event excess in a deeper energy region.
    - Come from a Y^* bound state? Y^* nucleus?

[3] Y. Ichikawa et al., PTEP **2020**, 123D01(2020)









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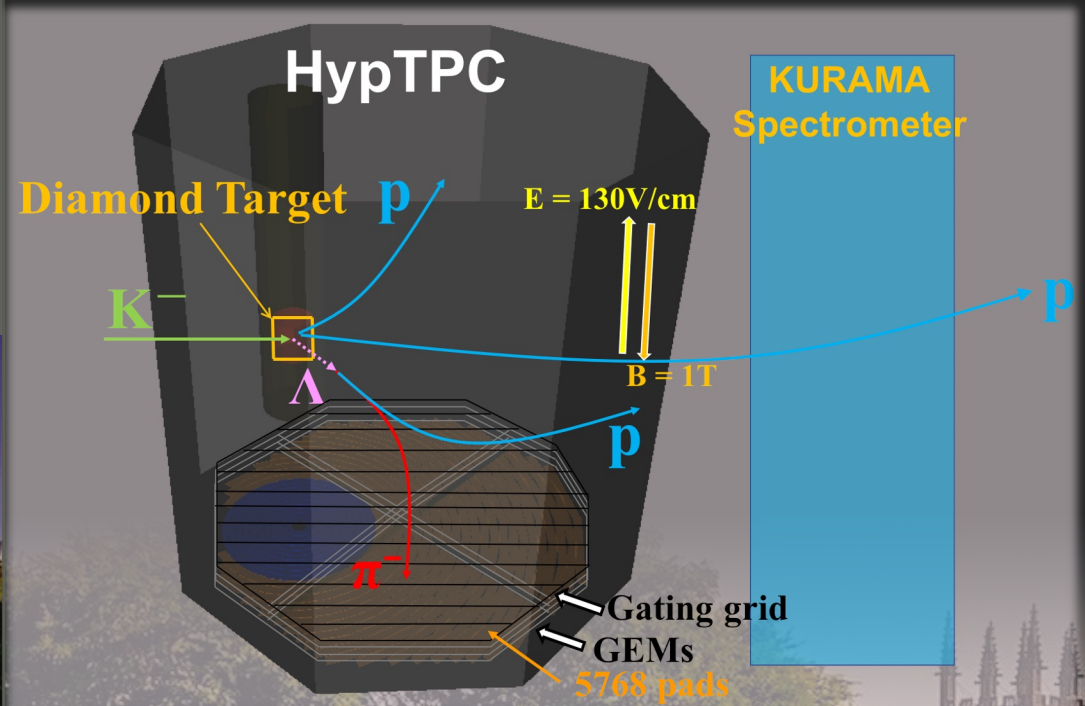
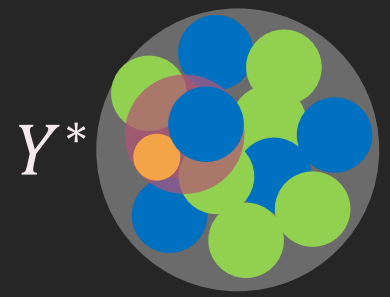
Byproduct1.

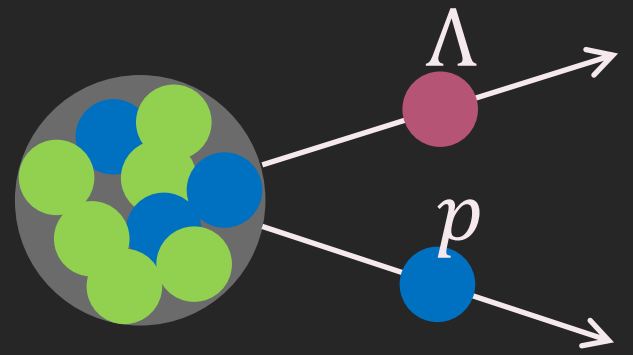
Kaonic nucleus search via $^{12}C(K^-, p)$

- In parallel with H search, we can search $\bar{K}$ nucleus via the same $^{12}\mathrm{C}(K^-, p)$
  Possible to measure decay particles $\Lambda\mathrm{p}$ using Time-Projection chamber, HypTPC
- Possible to observe a clear bump structure with good S/N ratio





$^{11}_{Y^*}\mathrm{Be}$



HypTPC

Measurement of $^{12}\mathrm{C}(K^-, p)$ missing mass with $\Lambda\mathrm{p}$ coincidence

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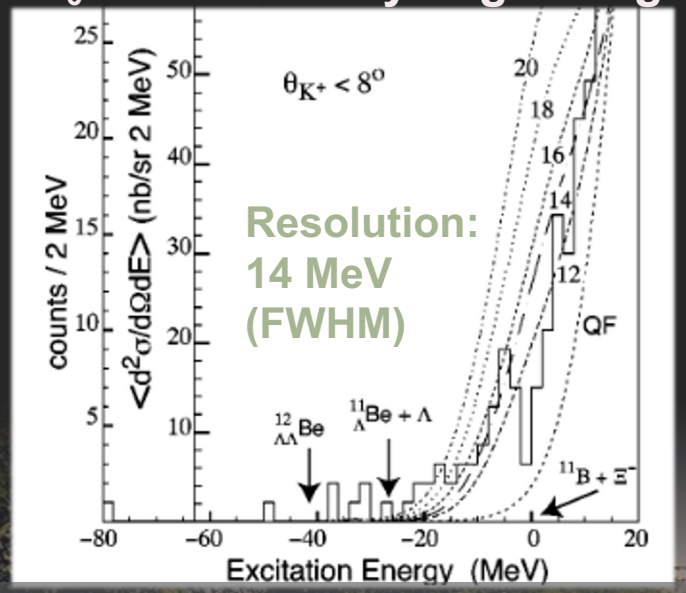
Byproduct2.

Measurement of Ξ^--*nucleus optical potential via* $^{12}C(K^-, K^+)$

- Many experiments have studied Ξ^--nucleus interaction but its imaginary part have not been well determined yet. Difficult to determine from the inclusive measurement.

BNL E885

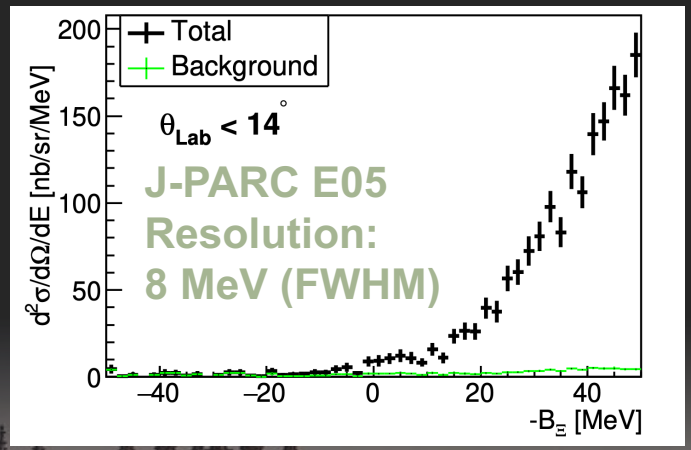
$^{12}C(K^-, K^+)$ inclusive spectrum
→ V_0^{Ξ} ~ -14 MeV by neglecting W_0^{Ξ}



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

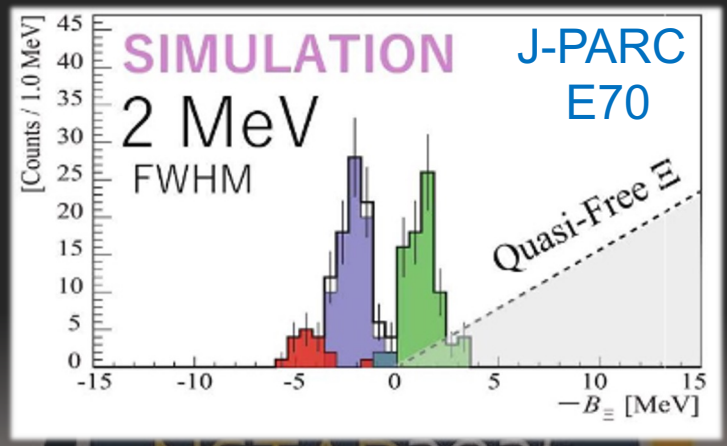
J-PARC E05/E70

$^{12}C(K^-, K^+)$ inclusive spectrum with wide B_{Ξ} range is taken.



Y. Ichikawa *et al.*, PTEP, to be published

Best resolution 2 MeV will be achieved in E70



T. Gogami *et al.*, EPJ Web Conf. 271, 1102 (2022).

Byproduct2.

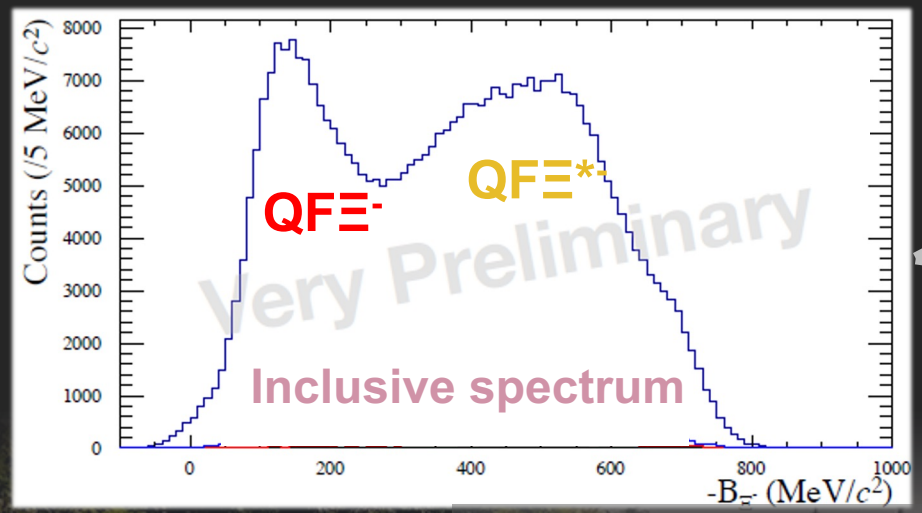
Measurement of Ξ^--*nucleus optical potential via* $^{12}C(K^-, K^+)$

- E42 experiment can investigate

  Ξ^- escape or $\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectra

  → Sensitive to the imaginary part of the potential!

$^{12}C(K^-, K^+)$ inclusive spectrum

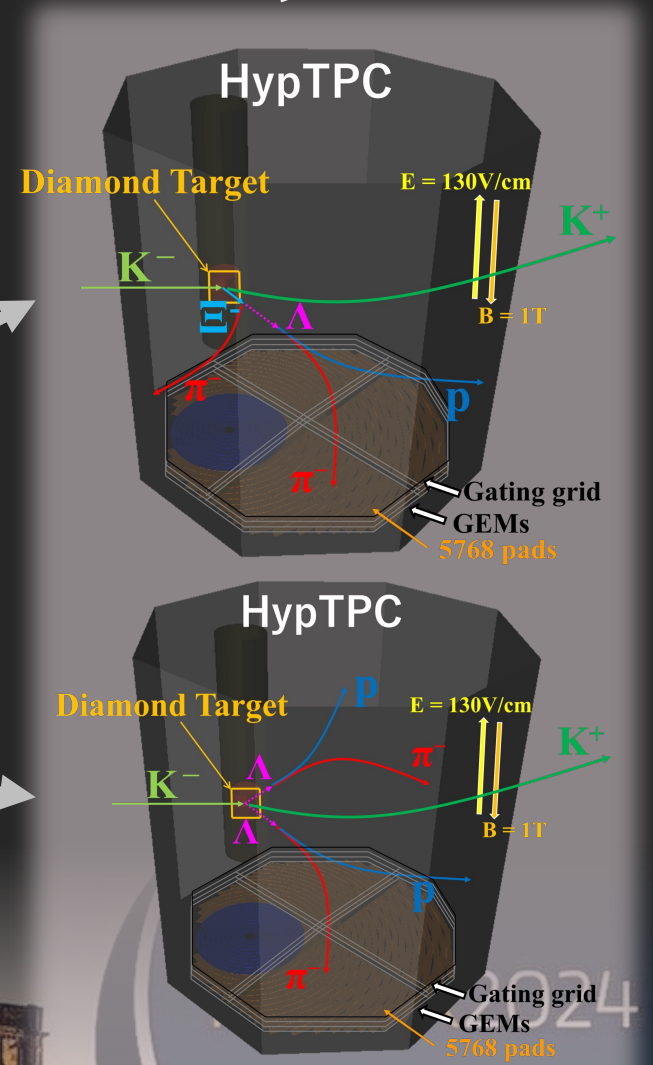


QFΞ^-: K^- "p"→ Ξ^- K^+

QFΞ^*: K^- "p"→Ξ^*(1535) K^+
K^- "p"→Ξ π K^+

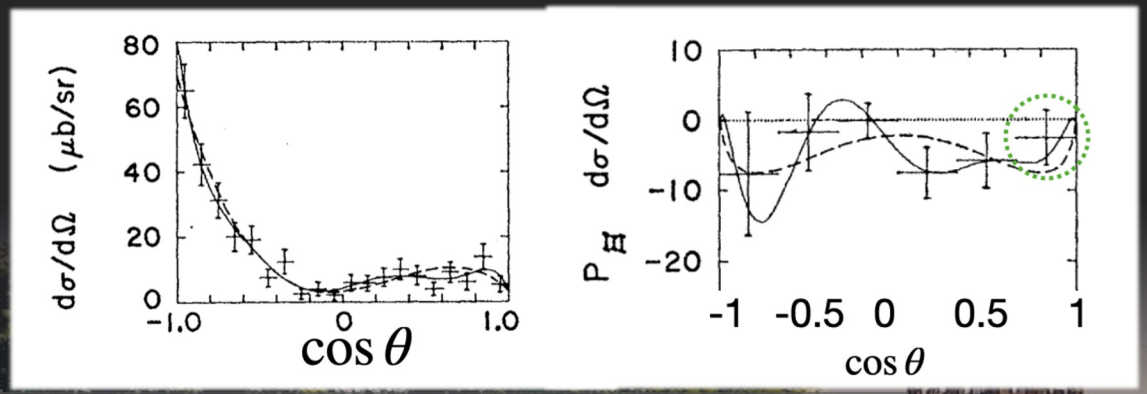
Ξ^- escape spectrum

$\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectrum

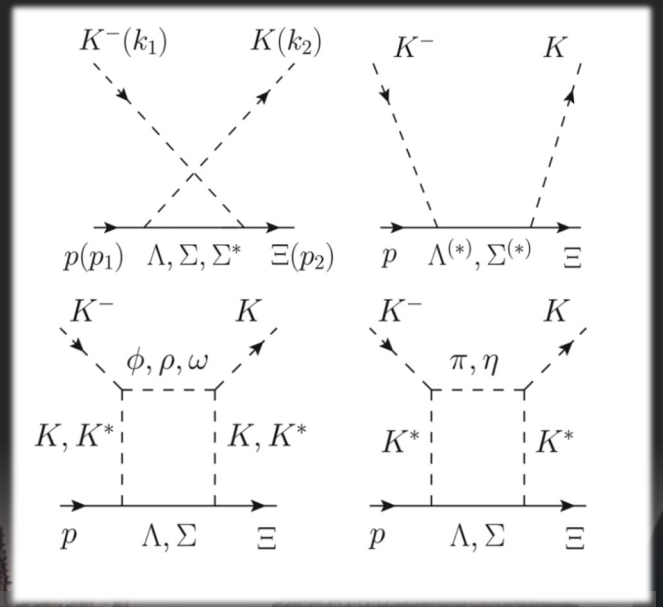


Polarization measurement of Ξ and $\Xi^*(1535)$ via $p(K^-, K^+)\Xi/\Xi^*$

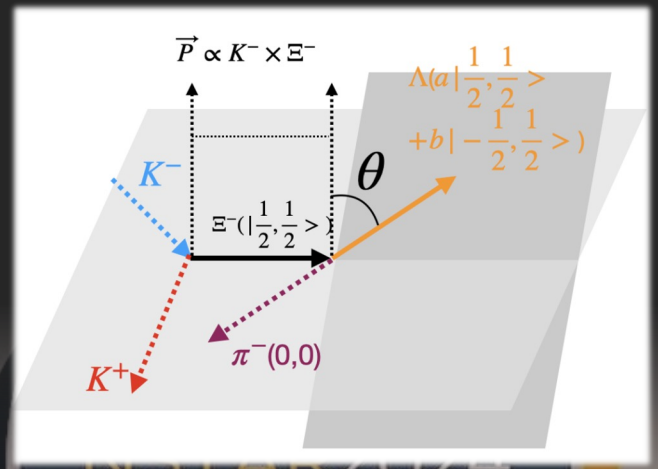
- Some "bump" structures in forward region of $p(K^-, K^+)\Xi^-$ with existing data [4]
- Accounted for by significant contribution from s-channel Λ(2100, 7/2-) and Σ(2300, 7/2+) [5]
- Polarization study is required to investigate the spin structure
- E42 can approach cosθ>0.83 region.
  - Decay amplitude → angular distribution
  - Angular distribution → polarization



[4] G. Burgun *et al.*, Nucl. Phys. B **8**, 447 (1968)



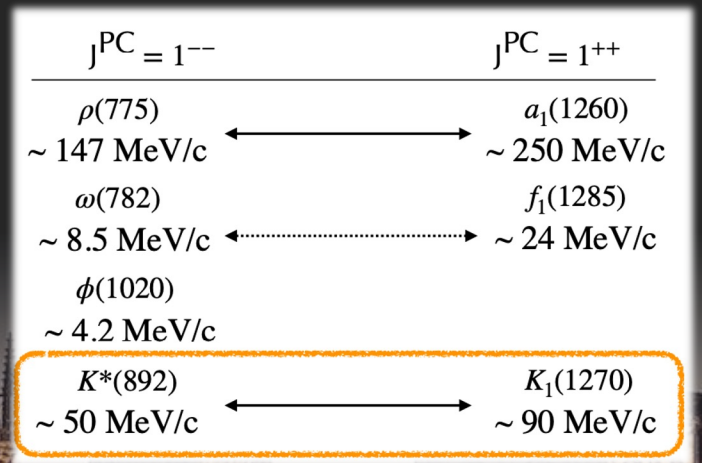
[5] S.H., Kim *et al.*
Phys. Rev. C **107**, 065202(2023)

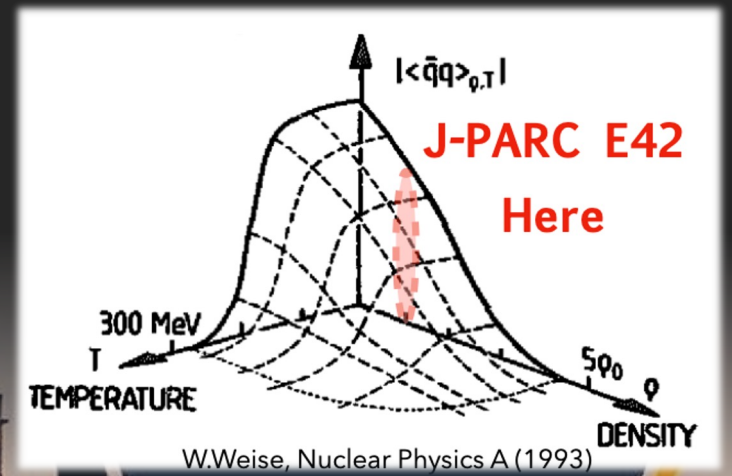


Study of ChSB effect by measuring $K^*(892)$ vector mass via $^{12}\mathrm{C}(K^-, p)$

- Chiral symmetry is believed to be partially restored in nuclear medium
- $K^*(892)$ are suitable for studying possible in-medium modification of mass because of smaller width of the mass than other meson candidates

- HypTPC can observe $K^*(892)$ by reconstructing $K_s^0 \rightarrow \pi^+\pi^-$ and finally $K^*(892) \rightarrow K_s^0\pi^-$





W.Weise, Nuclear Physics A (1993)

Summary

- H-dibryon search
  - Existence and properties of H-dibaryon are still under discussion
  - We performed a new search experiment called E42 at J-PARC using TPC
  - TPC analysis is ongoing for opening the H-dibaryon box soon

- Byproducts
  1. Kaonic nucleus search via exclusive $^{12}\mathrm{C}(K^-, p)$ reaction
  2. Measurement of Ξ-nucleus optical potential via $^{12}\mathrm{C}(K^-, K^+)$
  3. Polarization measurement of Ξ and $\Xi^*(1535)$ via $\mathrm{p}(K^-, K^+)\Xi/\Xi^*$
  4. Study of ChSB effect by measurement of $K^*(892)$ vector mass via $^{12}\mathrm{C}(K^-, p)$
  - We are analyzing data for these topics in parallel. Many, new results are coming soon!