Search for an H-dibaryon near $\Lambda\Lambda$ and $\Xi^- p$ thresholds at J-PARC

J-PARC E42

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Hadron & Nuclear Physics Lab

Perhaps a Stable Dihyperon

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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)

- MIT bag model predicts di-hyperon state (H) with

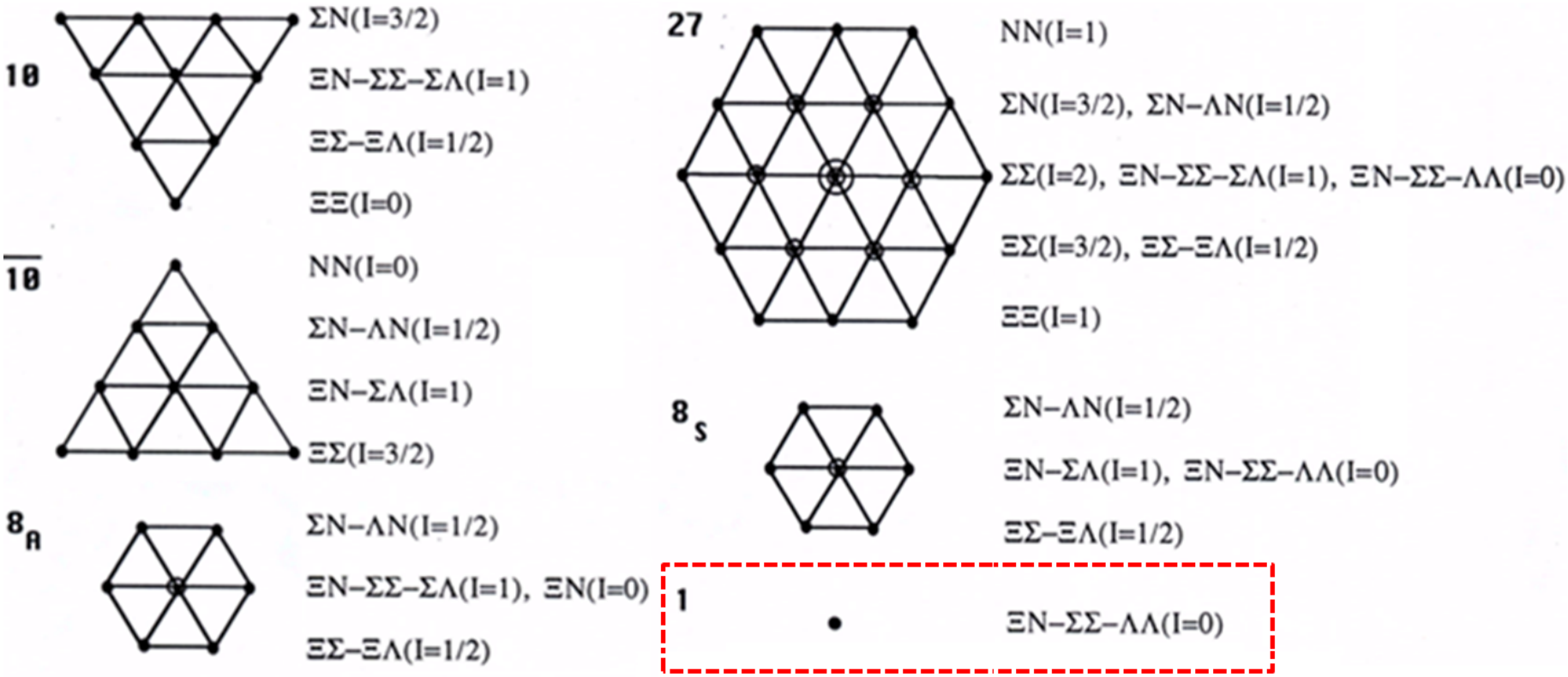
$$I = 0, \quad S = -2, \quad J^p = 0^+$$

and a mass of $m_H = 2150$ MeV (by 80 MeV relative to $2m_\Lambda$).

- This hypothesis initiated a world-wide activity in theoretical predictions and numerous experimental searches.

H-Dibaryon (Hexaquark State)

- A stable $SU(3)_f$ singlet hexaquark state consisting of $uuddss$ quarks due to QCD color magnetic force : H-Dibaryon ($J = 0, I = 0$)

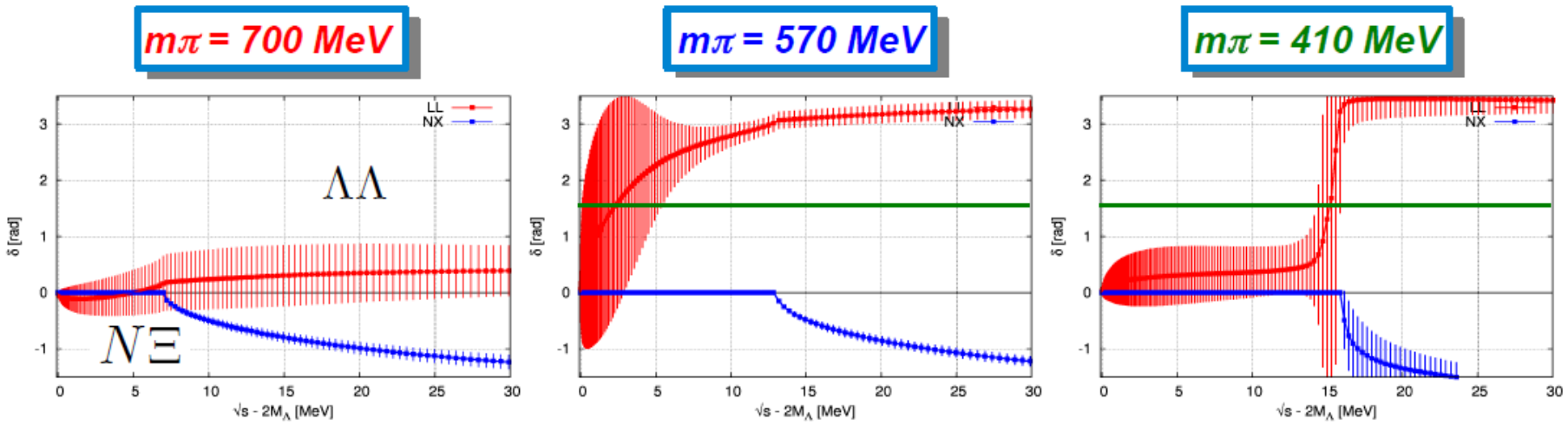


40 Year History since the H-Dibaryon Prediction

- 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.
- 2013-2015 — No evidence for $H \to \Lambda p \pi^-$ and $H \to \Lambda\Lambda$ in high-energy e^+e^-, pp and AA experiments
- 2011 — LQCD calculations predict the H-dibaryon to appear near (just above) threshold
- Present — **J-PARC E42 under preparation**

H-Dibaryon from Lattice QCD[1]

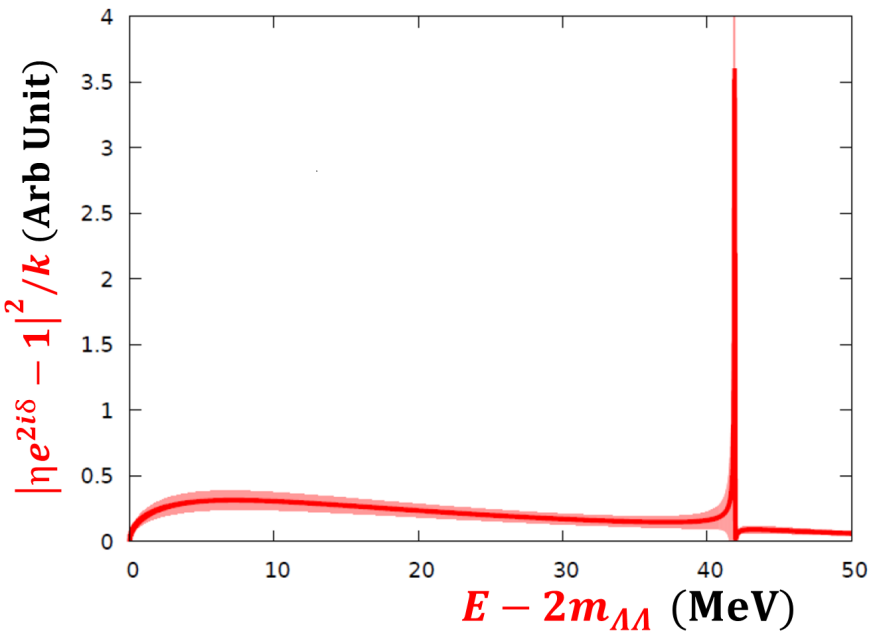
- Success of recent LQCD calculations in reproducing NN interactions revived the H-dibaryon search.
- Lattice QCD calculations predict the H appears closer to $N\Xi$ mass threshold with physical quark masses, yielding a bound $N\Xi$ system at $m_\pi = 410$ MeV.

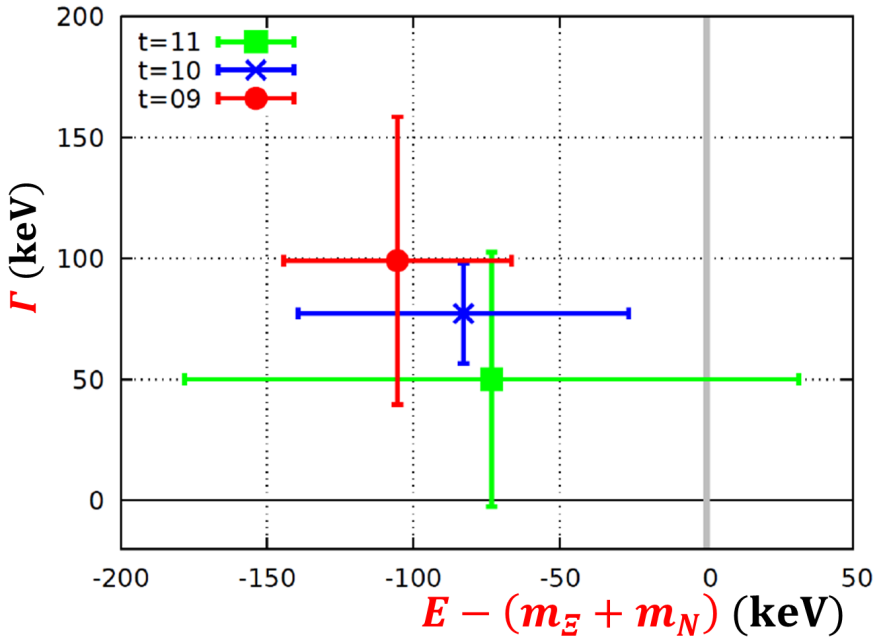


[1]S. Aoki (HAL Collab.), Nuclear Physics from Lattice QCD, 2016.

Recent Lattice QCD Calculation Result

- Preliminary results with $L = 8$ fm and $m_\pi = 145$ MeV.
- $\Lambda\Lambda$ and $N\Xi$ $(I = 0)$ $^1S_0$ phase shifts [2]

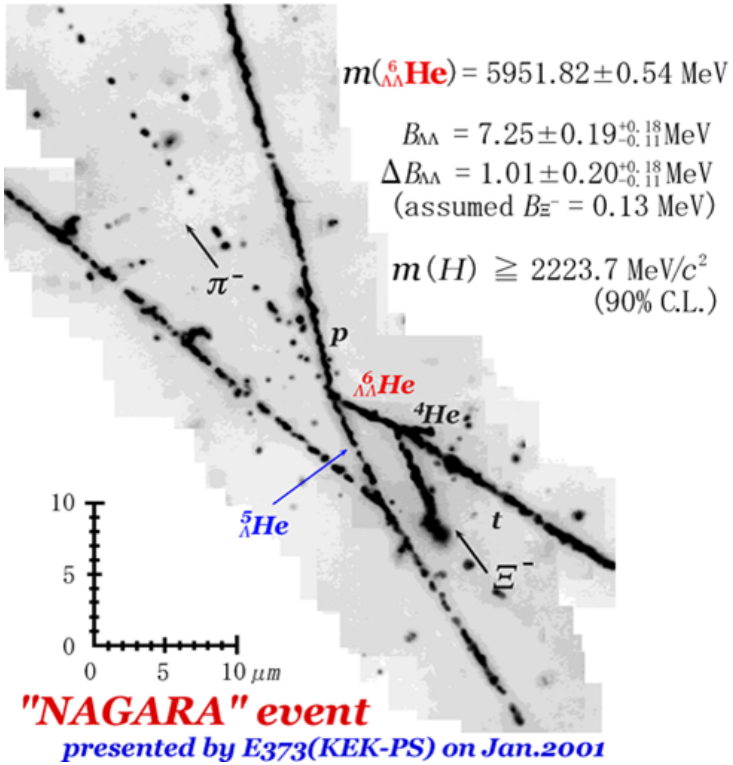


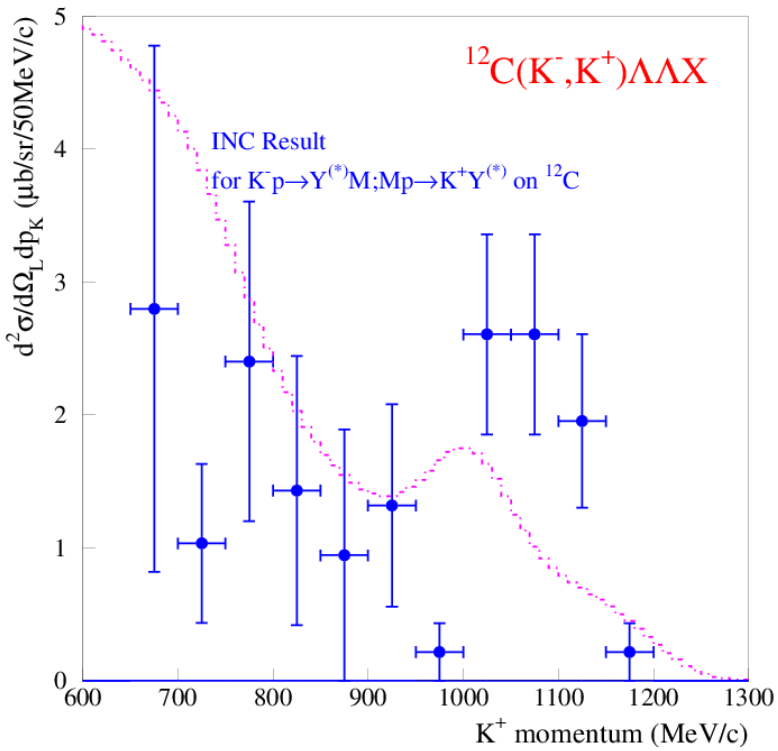


- Deuteron-like $N\Xi$ bound system from ESC model.[3]

[2] K. Sasaki for the HAL Collab., Reimei 2016, Inha (2016).
[3] Y. Yamamoto, NSMAT2016

Double-Λ Hypernuclei and ΛΛ Production



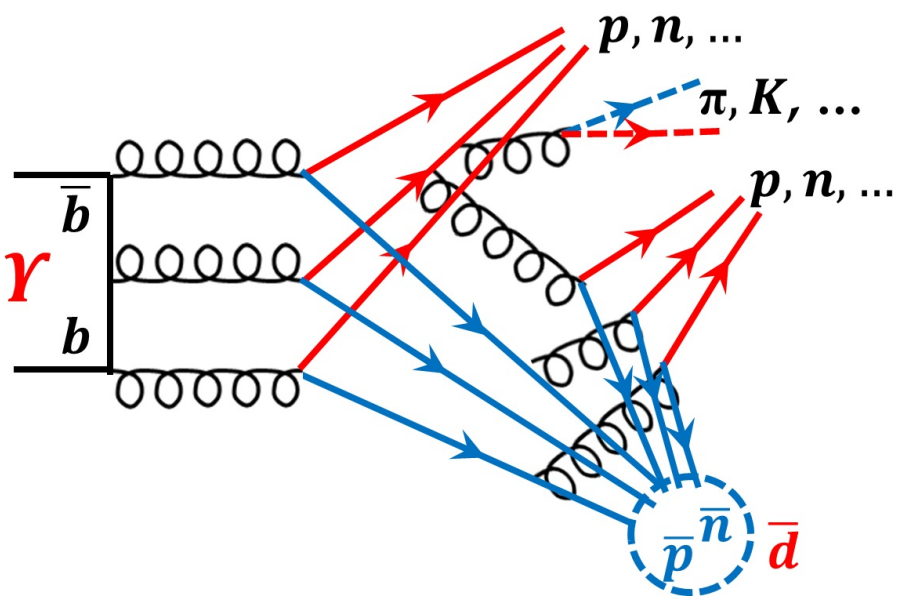


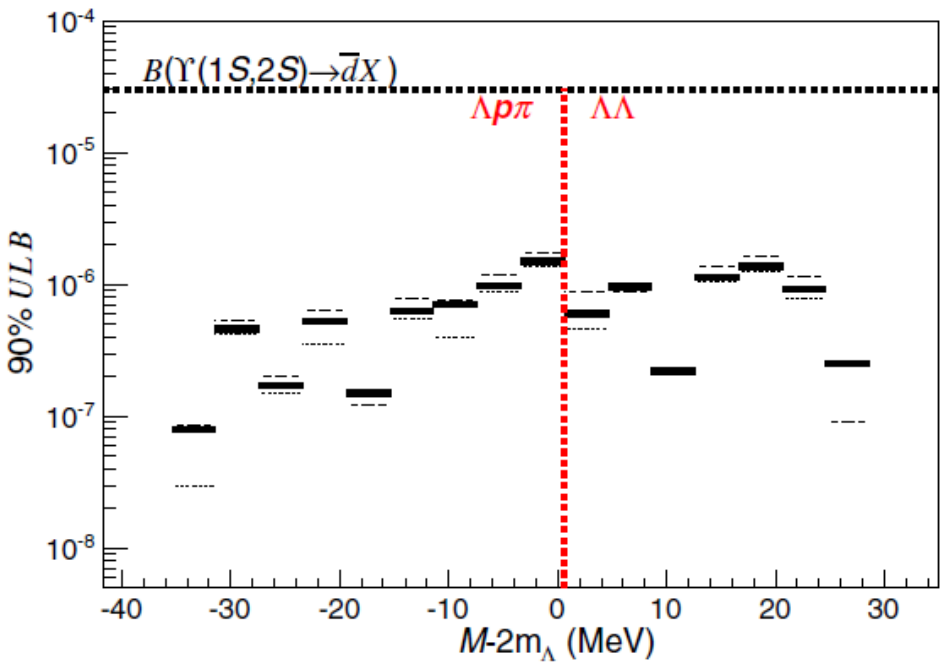
- ΛΛ pair decays strongly to the H in a nucleus if H is lighter than ΛΛ in a nucleus.

- KEK-E224 measurement for $^{12}\mathrm{C}(K^-, K^+)\Lambda\Lambda X$ (7.6 μb/sr and 3 μb/sr for the H)

H-Dibaryon Search at Belle [4]

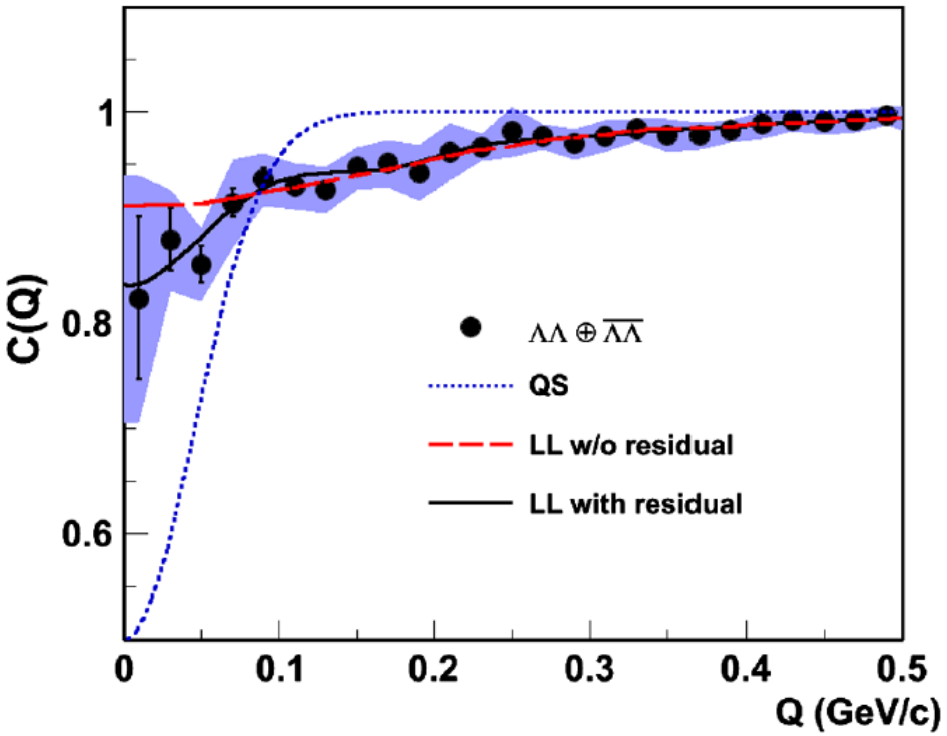
- The Belle searched for the H-dibaryon in Υ decays ($\mathrm{Br}(\Upsilon \to HX)/\mathrm{Br}(\Upsilon \to \bar{d}X) < 10^{-2}$).
- Six-quarks should be produced and correlated to form the H-dibaryon from nothing in the intial state.

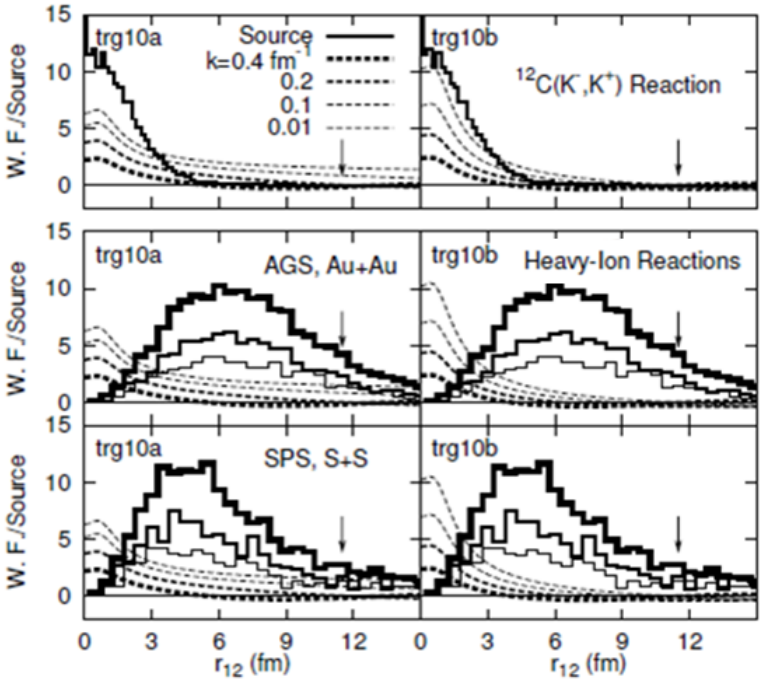




[4] B.H. Kim *et al.*, Phys. Rev. Lett. 110 (2013)

$\Lambda\Lambda$: Recent Results from STAR [5]





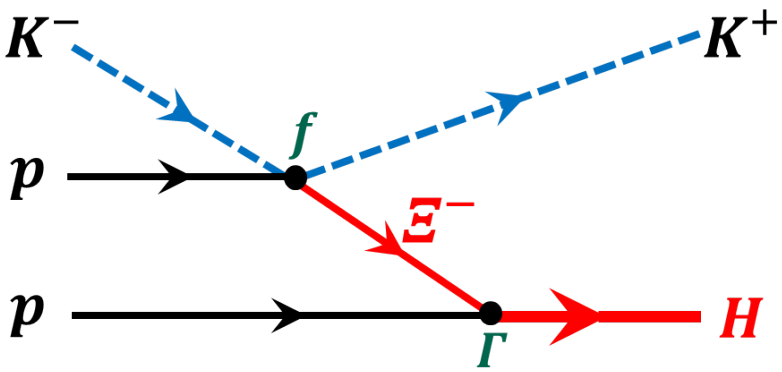
- Only small fraction of $\Lambda\Lambda$ or ΞN pairs will be produced close enough in space and with their relative momenta small enough to interact via H-formation.

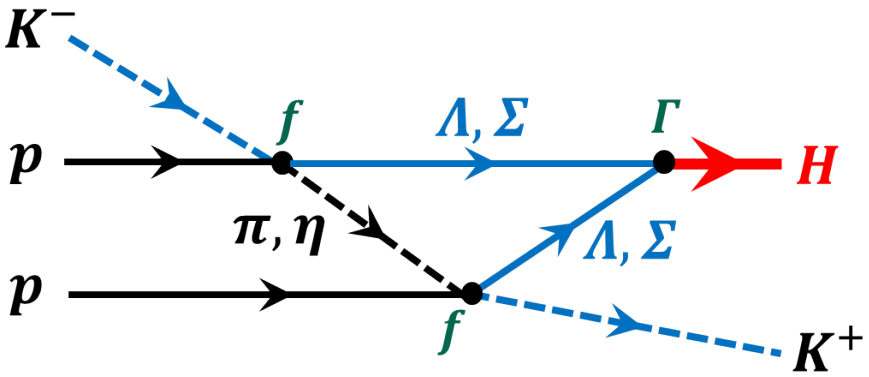
[5] STAR Collab., Phys. Rev. Lett. 114, 022301 (2015); A. Ohnishi, HHI (2012).

H Production from (K^-, K^+) Reactions

$$K^- + (pp)^1S_0 \rightarrow K^+ + (\Xi^- p)^1S_0 \rightarrow K^+ + H(J^\pi = 0^+)$$

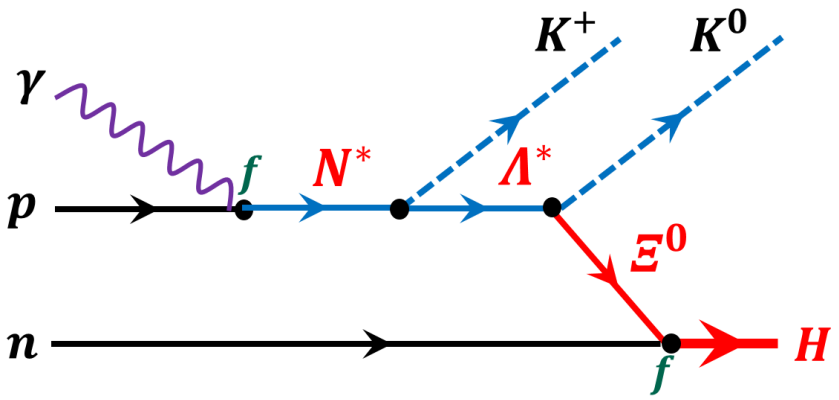
- Possible H production processes on a diproton pair via the (K^-, K^+) reaction[6] [7] :

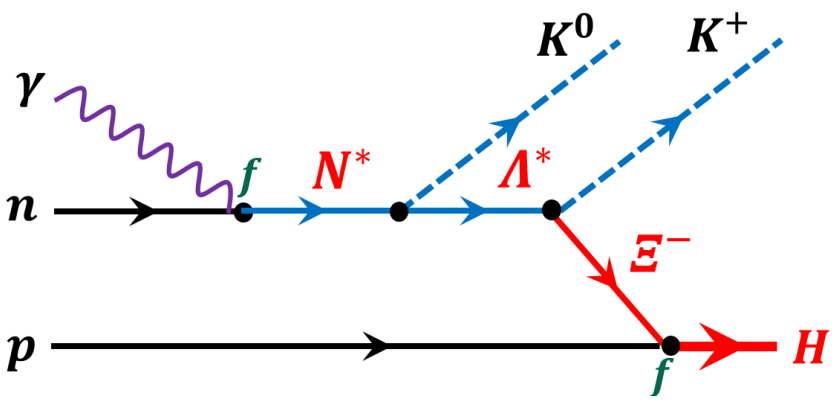




[6] N. Aizawa and M. Hirata, Z. Phys. A 343, 103 (1992)
[7] A.T.M. Aerts and C.B. Dover, Phys. Rev. D28, 450 (1983)

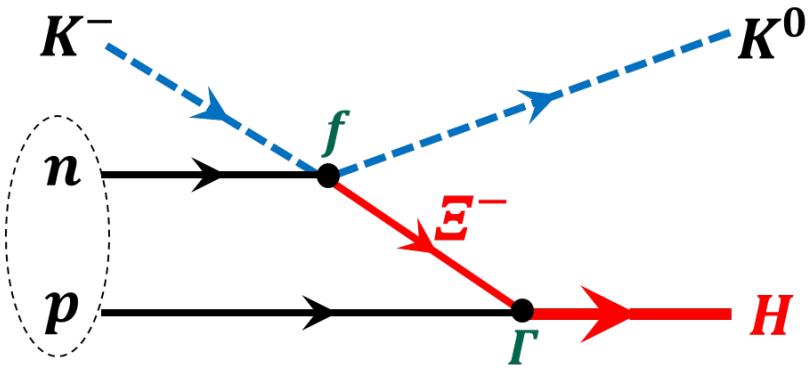
H-Dibaryon Search from Photoproduction

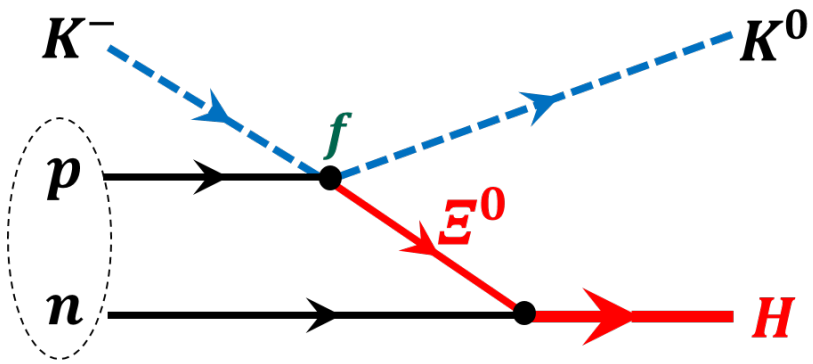




- H-dibaryon search from photoproduction ($E_\gamma^{\rm th} = 1.83$ GeV for $m_H = 2m_\Lambda$) is viable at SPring-8 and J-Lab.
- $\gamma d \to K^+ K^0 H$ followed by $K^0 \to \pi^+\pi^-$.
- $\gamma p \to K^+ \overline{K}^0 n$ $(a_0^+ \to K^+\overline{K}^0)$; $\gamma n \not\to K^+ \overline{K}^0 X$

H-Dibaryon Search from $K^- d \to H K^0$ Reaction





- Background from a charge-exchange reaction $K^- p \to \overline{K}^0 n$
- A liquid ^{3}He target could provide a pp pair, but a solid denser target is better suited for an effective di-proton target such as ^{12}C and ^{63,65}Cu.

H-Dibaryon Search at J-PARC : E42

The existence of the H-dibaryon still awaits definitive experimental confirmation or exclusion.

- Weakly-bound : $H \to \Lambda p \pi^-$
- Virtual state : $\Lambda\Lambda$ threshold effect
- Resonance : Breit-Wigner peak in the $\Lambda\Lambda$ mass spectrum

J-PARC-E42 EXPERIMENT

1. in $(\Sigma^- p)$, $\Lambda p \pi^-$, $\Lambda\Lambda$ and $\Xi^- p$ channels
2. by tagging the $S = -2$ system production
3. via (K^-, K^+) reactions at 1.7 GeV/c with a diamond target.
4. Hyperon Spectrometer : 1 MeV $\Lambda\Lambda$ mass resolution!

The J-PARC E42 Collaboration

J.K. Ahn (*spokesperson*), S.W. Choi, W.S. Jung, S.H. Kim, Y.J. Kim, J.W. Lee, Y. Han, S. Hasegawa, R. Honda, Y. Ichikawa, K. Imai (*co-spokesperson*), H. Sako, S. Sato, H. Sugimura, K. Tanida, S.B. Yang, M. Ieiri, R. Kiuchi, M. Naruki, K. Ozawa, H. Takahashi, T. Takahashi, S.H. Hwang, S.H. Kim, H.S. Lee, S.Y. Ryu, K. Shirotori, H. Ekawa, H. Fujioka, M. Niiyama, S. Kinbara, K. Nakazawa, M. Sumihama, J. Yoshida, B. Bassalleck, K. Hicks, C. Rangacharyulu, L. Guo, K. Miwa, S. Hayakawa, Y. Nakada

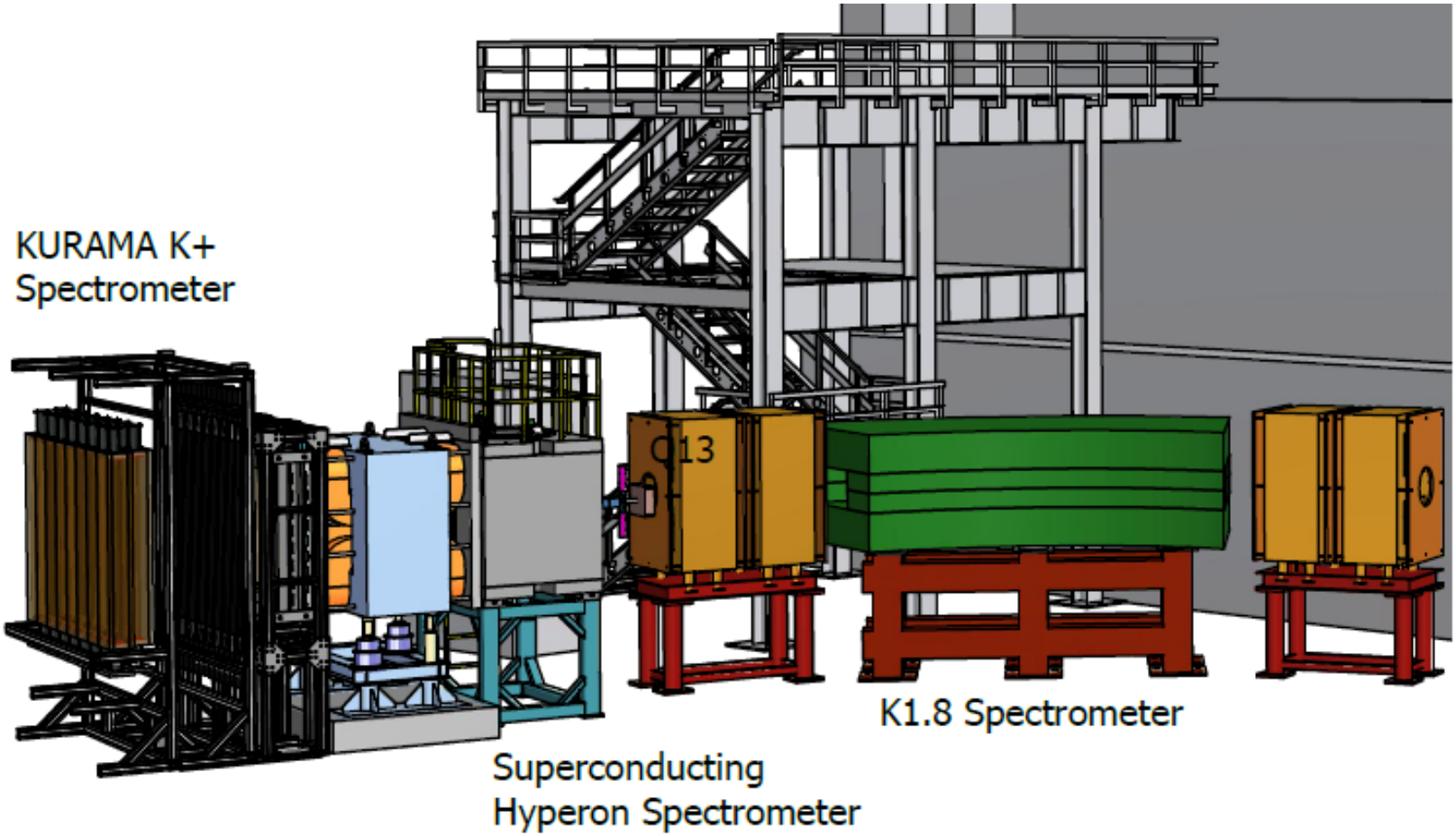
[1] *Korea University / Korea Research Institute of Standards and Science / Institute for Basic Science / Seoul National University, Korea*

[2] *Japan Atomic Energy Agency (JAEA) / High Energy Accelerator Research Organization (KEK) / RCNP, Osaka University / Kyoto University / Gifu University / Tohoku University / Osaka University, Japan*

[3] *Ohio University / University of New Mexico / Florida International University, USA*

[4] *University of Saskatchewan, Canada*

Hyperon Spectrometer at K1.8 Beam Line of J-PARC



- The Hyperon spectrometer consists of a time projection chamber (HypTPC) and the superconducting Helmholtz magnet.

Superconducting Dipole Magnet

- Helmholtz-type dipole magnet[a]
- B field at center : 1.5 T (1.0 T for E42)
- Conduction cooling with two GM refrigerators
- Field uniformity $B_r/B_y < 1\%$ over the inner volume (ϕ = 500 mm)

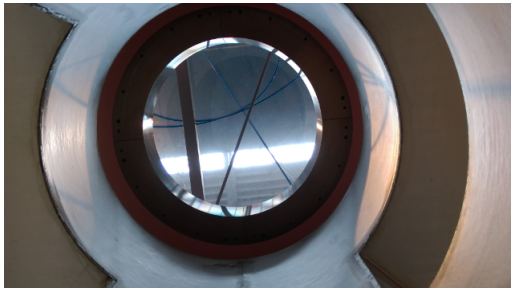
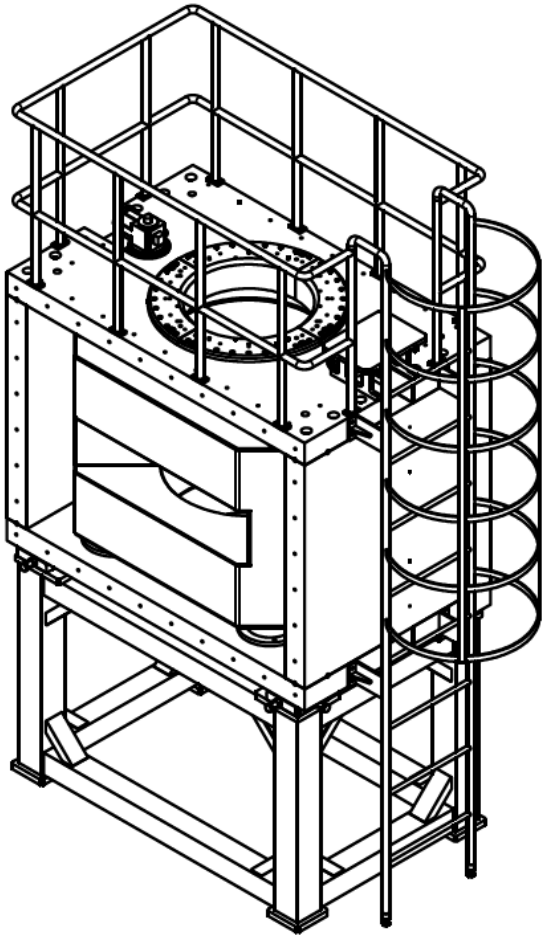


Photo of inner volume (ϕ = 800 mm)

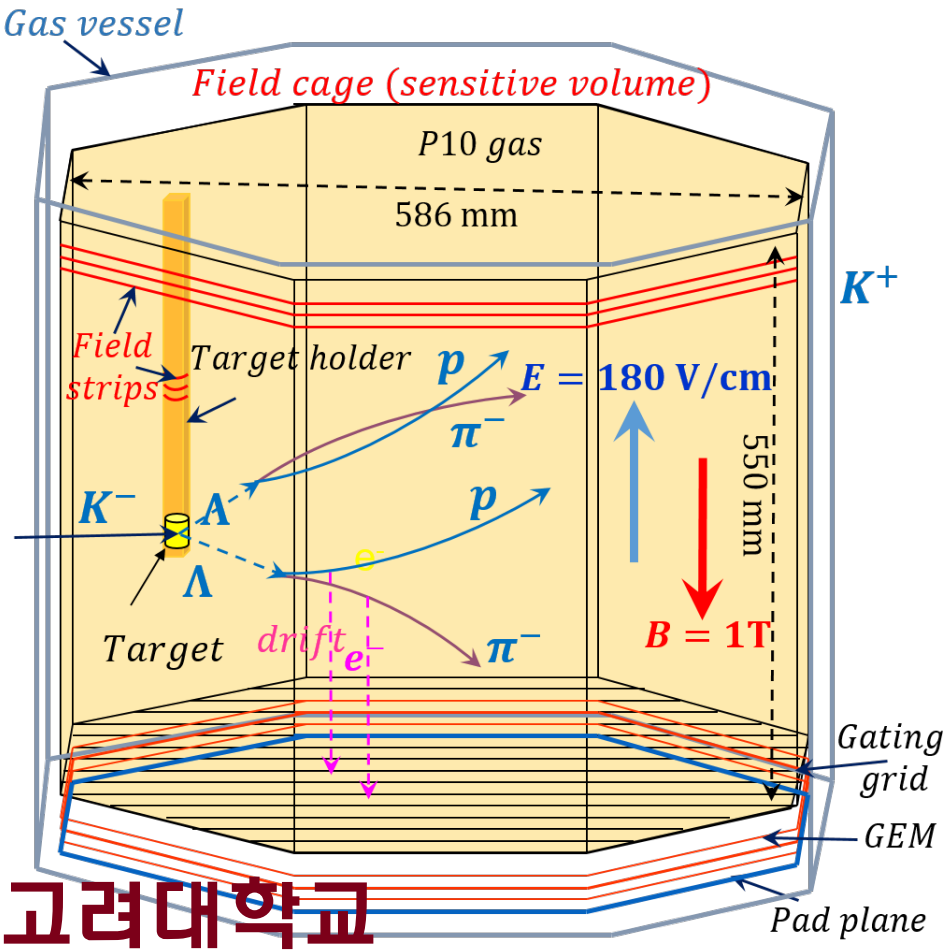
Photo of the Helmholtz magnet for field measurement

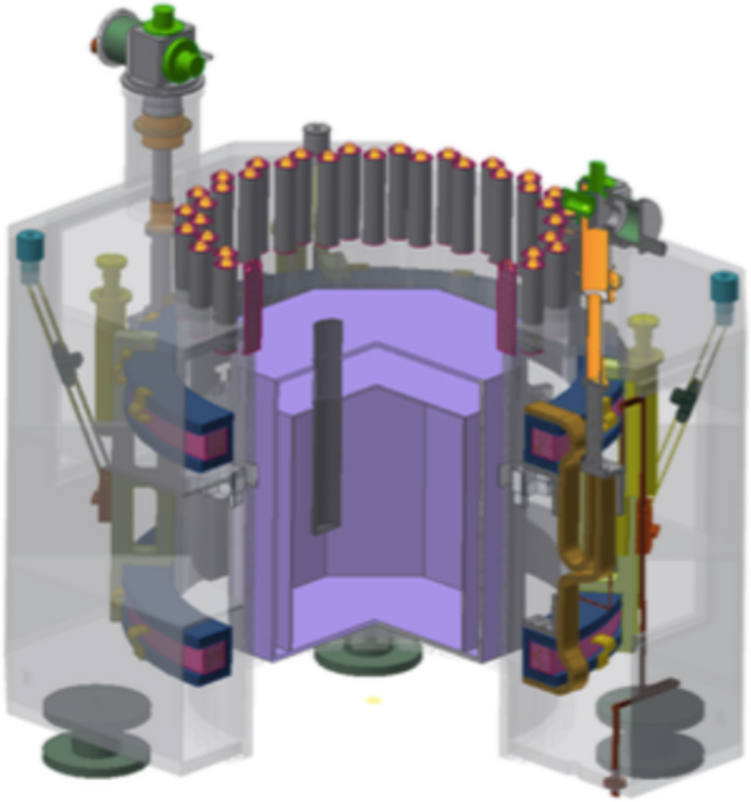


[a]KR-tech, Daegu, Korea

Time Projection Chamber

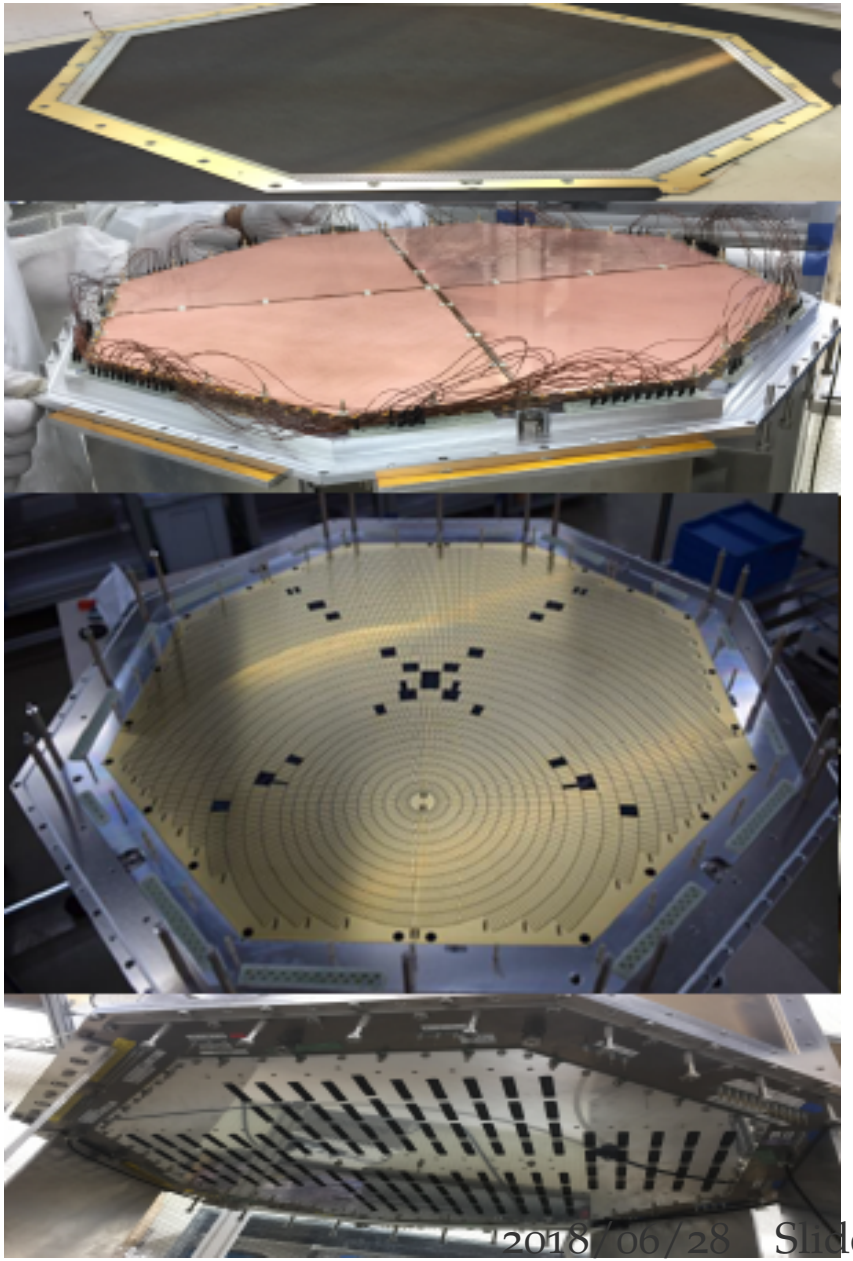
- Octagonal prism field cage and a readout chamber consisting of a gating-grid, a triple GEM layer and a concentric pad plane (5768 pads)



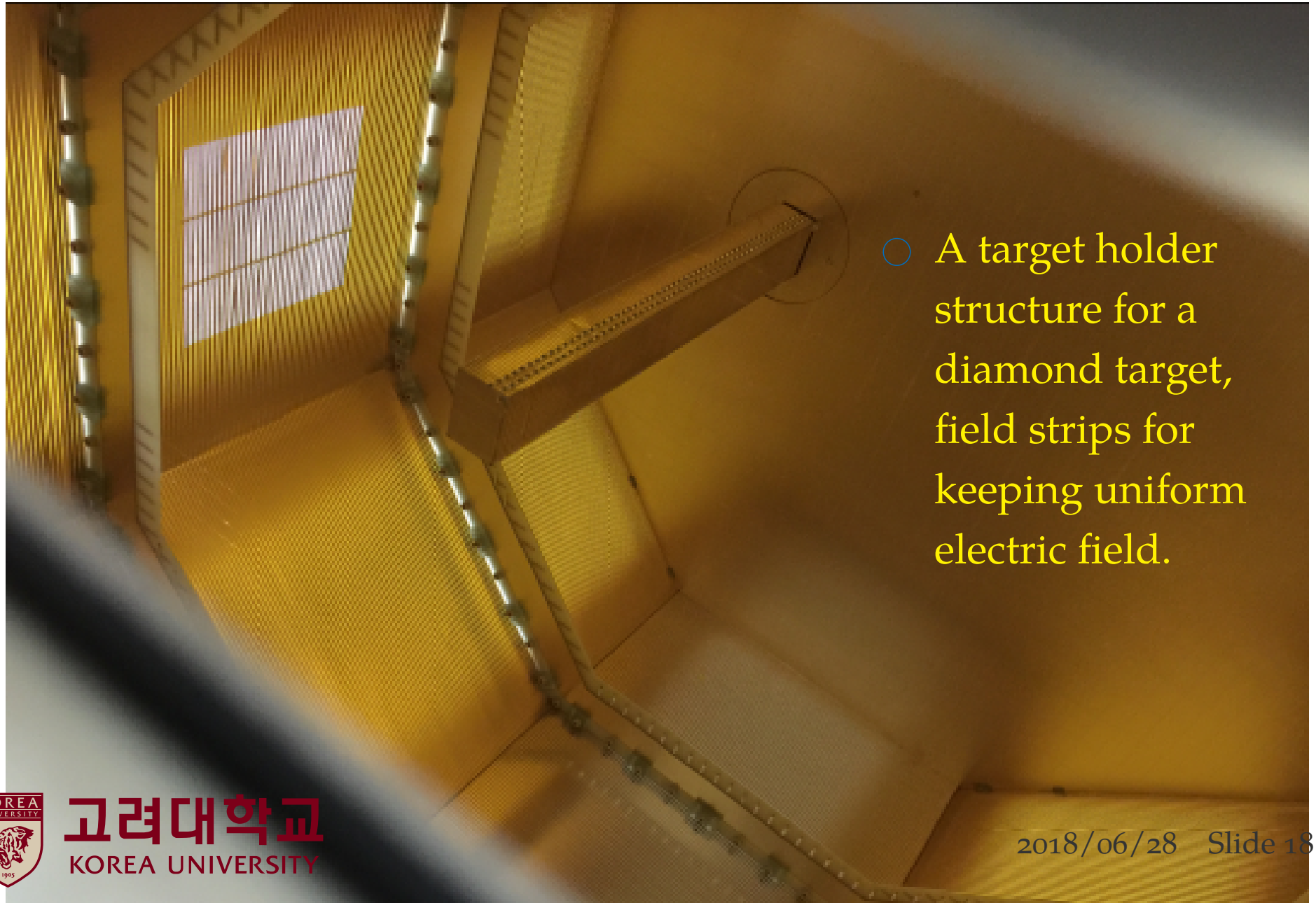


HypTPC Structure

- Four GEM (250×250 mm^2) sheets per layer
- Triple GEM layers (100 μm (top) + 50 μm + 50 μm)
- Gain $\sim 10^4$
- 10 inner pad rows with 2.1-2.7 $\times$ 9 mm^2.
- 22 outer pad rows with 2.3-2.4 $\times$ 12.5 mm^2.
- Position resolution $<$ 300 μm
- $\Delta p/p$ = 1-3% for π and p.

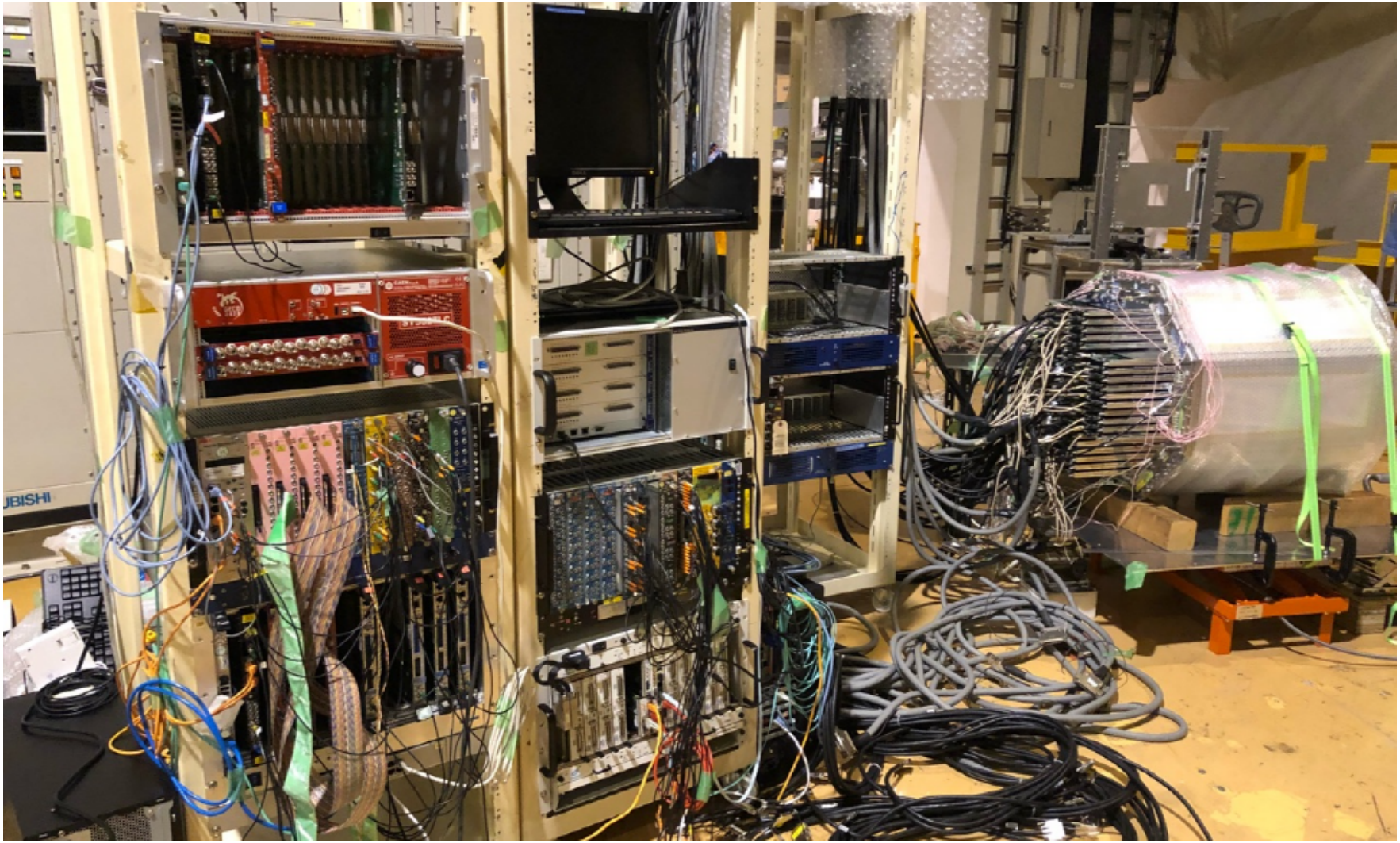


Inside the HypTPC

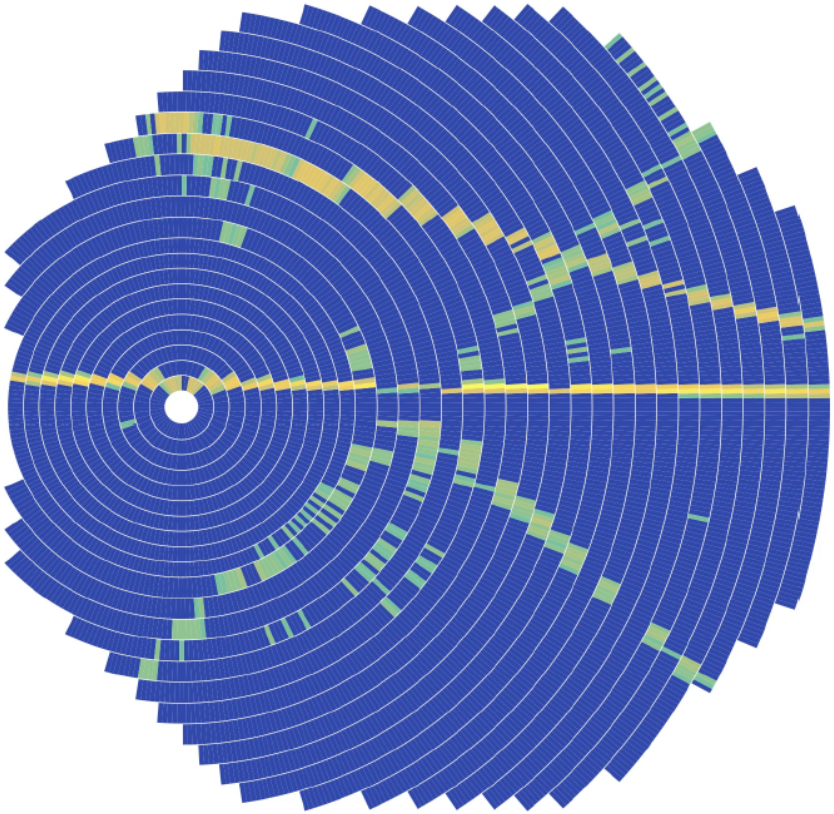


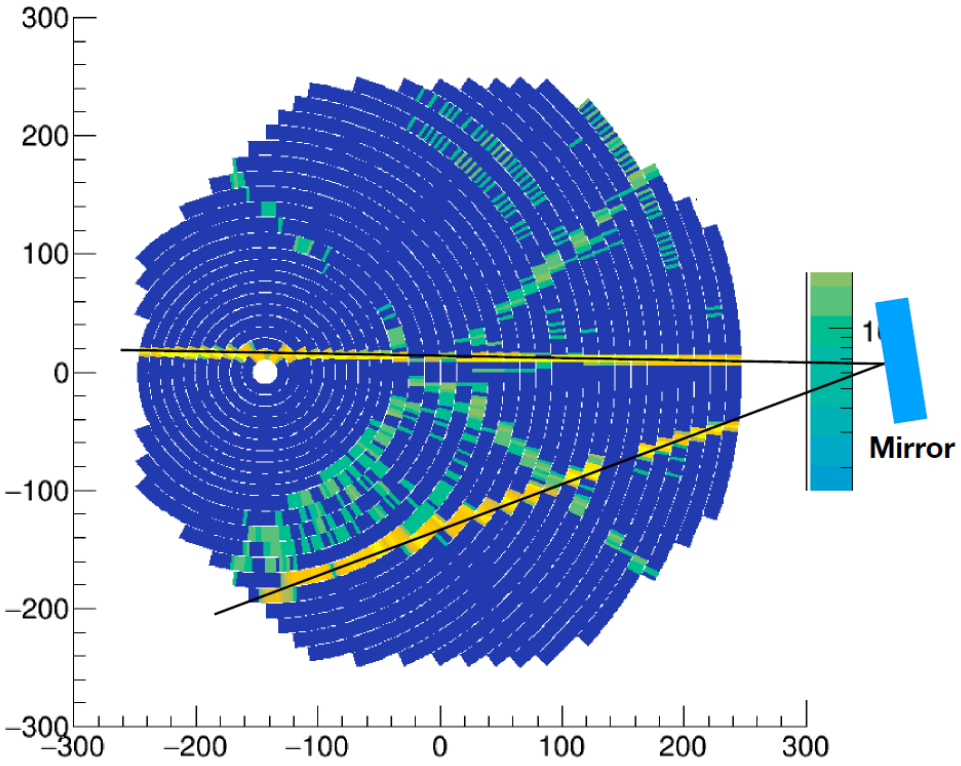
- A target holder structure for a diamond target, field strips for keeping uniform electric field.

Proton Beam Test at HIMAC



Laser Tracks in HypTPC [8]





[8] S.H. Kim, *Development of the Hyperon Spectrometer for Hadron Physics Experiments at J-PARC*, Poster Presentation, June 27.

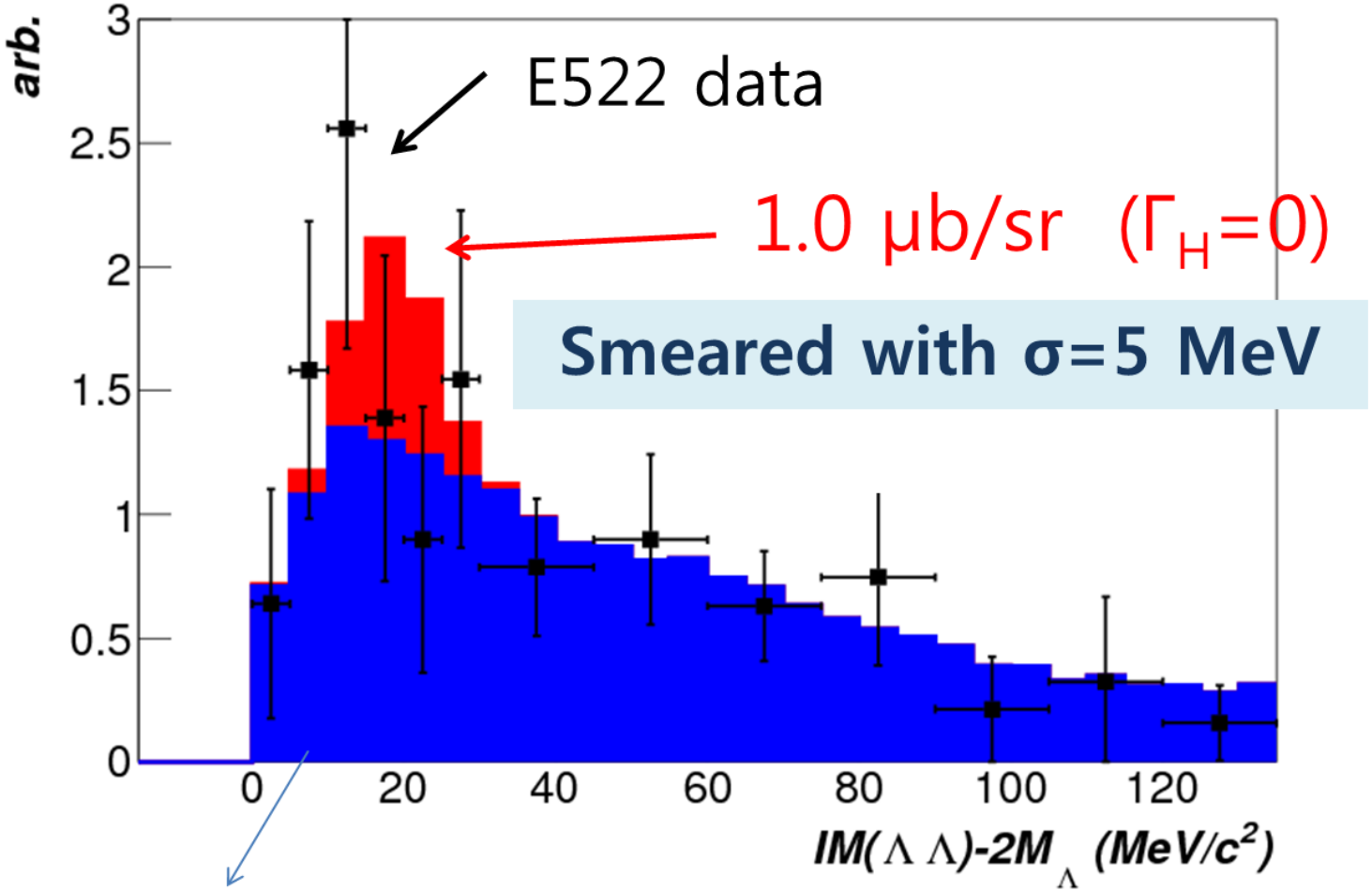
Yield Estimate

Parameters	Value
K^- beam	6×10^5 K^-/ spill (5.5 s)
Target length	20 mm
Number of nuclei	$2.65 \times 10^{23}/\mathrm{cm}^2$
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr
$\Delta\Omega(K^+)$	0.16 sr
$\mathrm{Br}(\Lambda \to p\pi^-)^2$	0.41
K^+ Reconstruction	0.5
$\Lambda\Lambda$ Reconstruction	0.4 – 0.6
Yield	0.03 event / spill

- 1.5×10^4 $\Lambda\Lambda$ events for 100 shifts at the current beam power.

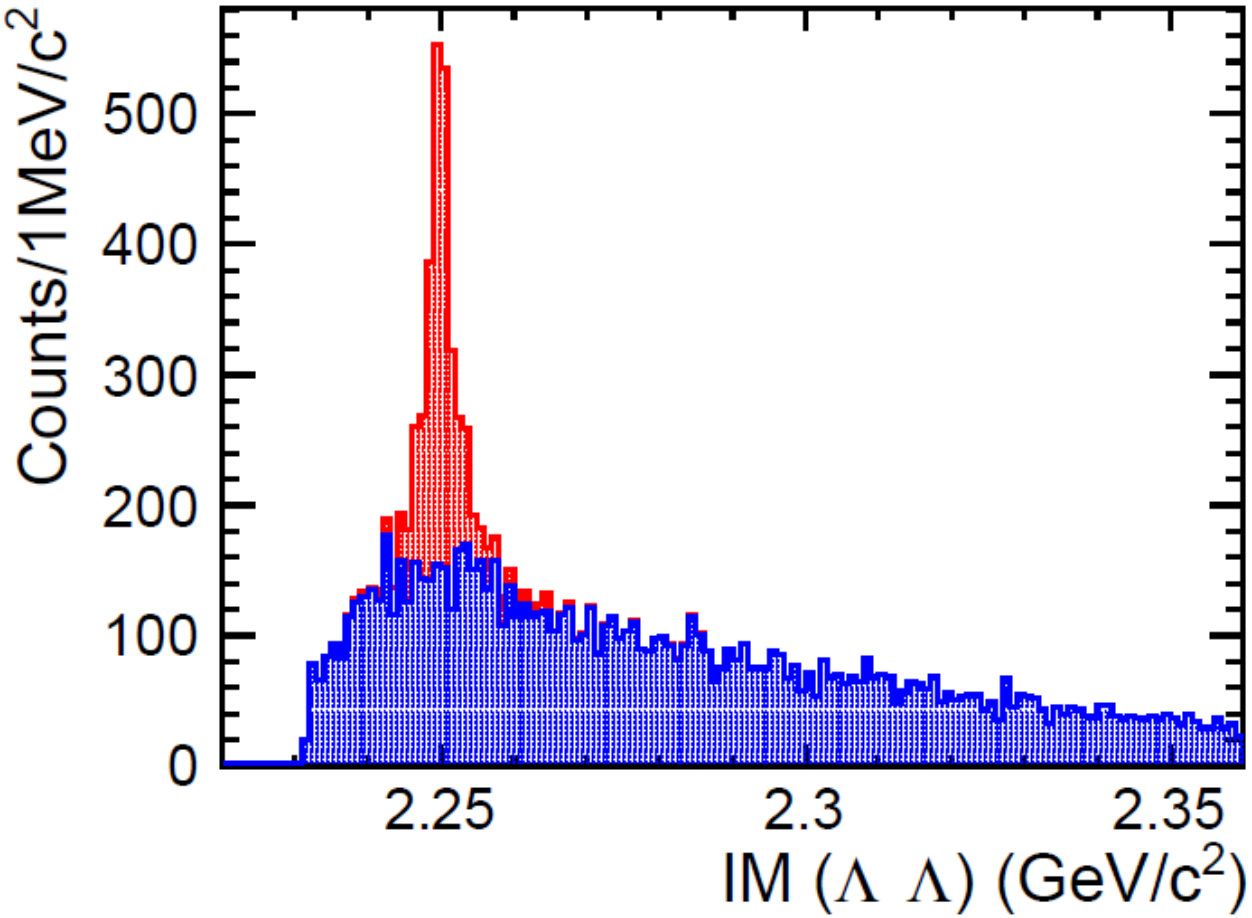
ΛΛ Mass Distribution from KEK-E522

Scintillating Fiber Target : 5 MeV ΛΛ mass resolution!



INC calculation results based on Ref (Y. Nara et al, NPA 614 (1997) 433)

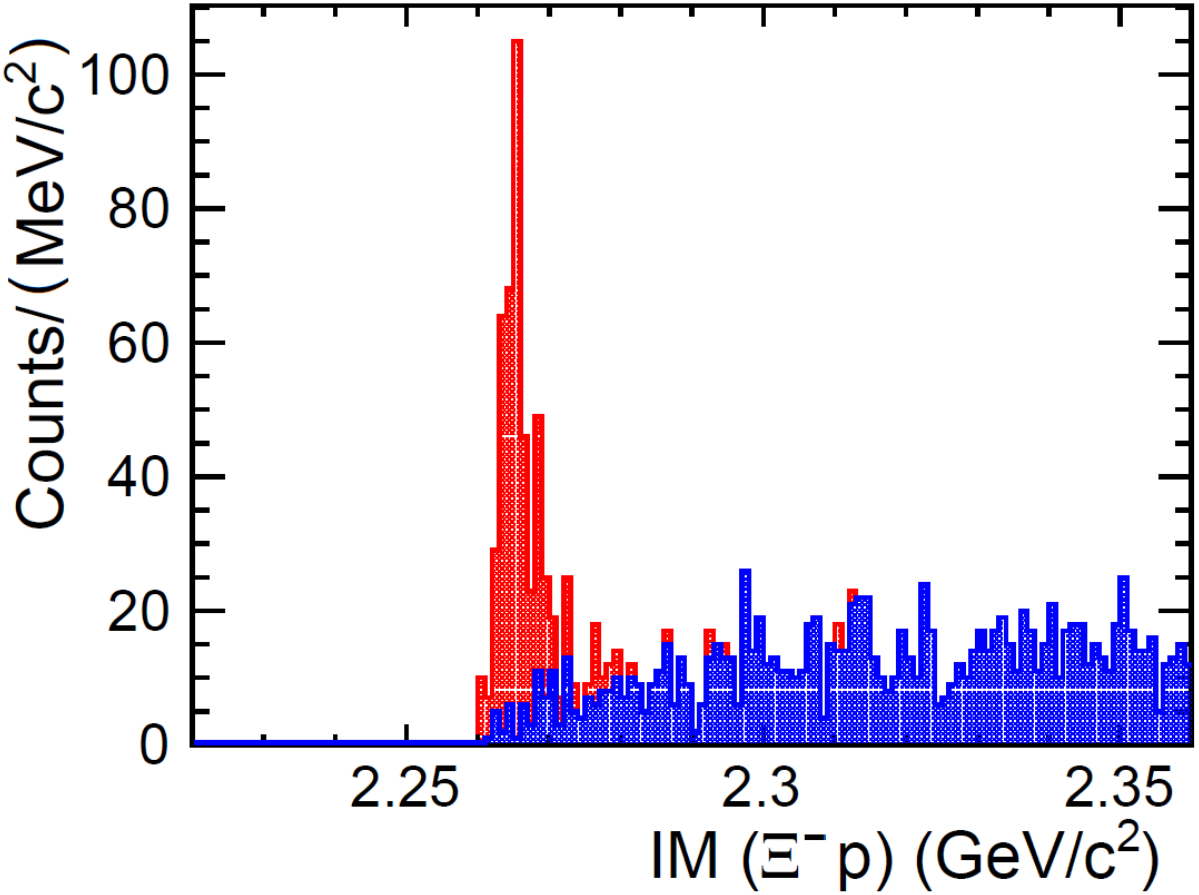
Simulated $\Lambda\Lambda$ Spectrum for $H(2250)$ [9]



Simulated $\Lambda\Lambda$ Spectrum for $H(2250)$ assuming $d\sigma/d\Omega = 1.0\ \mu$b/sr.

[9] Simulation on two-step processes is based on INC calculation by Y. Nara, A. Ohnishi, T. Harada and A. Engel, Nucl. Phys. A614 (1997) 433.

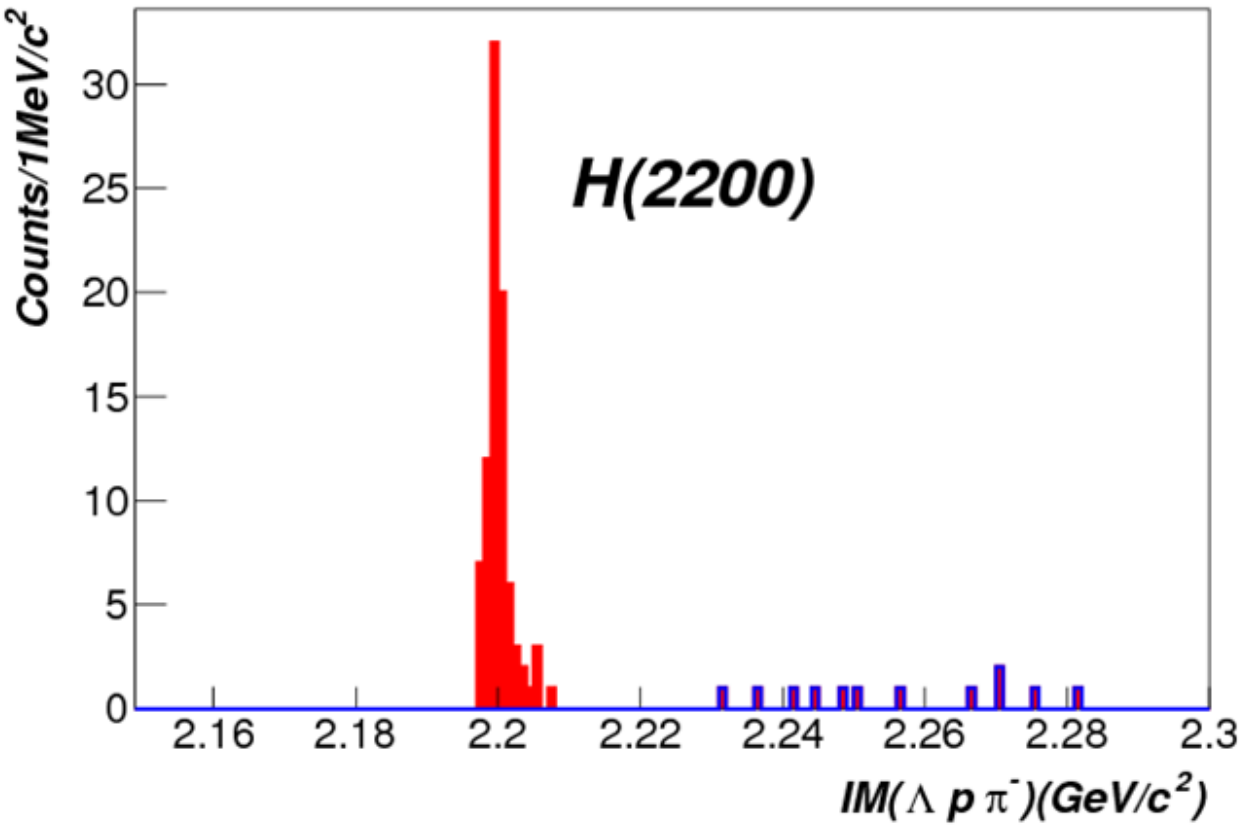
Simulated $\Xi^- p$ Spectrum for $H(2265)$ [10]



Simulated $\Xi^- p$ Spectrum for $H(2265)$ assuming $d\sigma/d\Omega = 0.3\ \mu b/sr$.

[10] Blue spectrum shows a phase-space distribution without $\Xi^- p$ final-state interactions.

Simulated $\Lambda p \pi^-$ Spectrum for $H(2200)$



- $\Lambda p \pi^-$ decays are almost free from background in (K^-, K^+) reaction at 1.8 GeV/c.

Anticipated Timeline for E42

	June	
2018	Jul	Proton Beam Test of HypTPC at HIMAC
	Nov	HypTPC Test with the Magnet
2019		
		Installation of Hyperon Spectrometer
		Commissioning of Hyperon Spectrometer
		E42 Physics Run
....	....	.....
2020		E42 Physics Run

$S = -2$ Dibaryons in Particle Data Book (1982)

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S=-2 DIBARYON Status: *

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108  BARYON NUMBER 2, STRANGENESS -2 STATES

        IN THIS SECTION WE USE THE FOLLOWING ABBREVIATIONS FOR MEASURED
        QUANTITIES--

        LLIM      LAMBDA-LAMBDA INVARIANT MASS
        LLPI      LAMBDA-LAMBDA-PI INVARIANT MASS
        XPIM      XI-P INVARIANT MASS

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                  108  B=2, S=-2 -- MASS (MEV)

M     A    (2367.0)    (4.0)          BEILLIERE 72 LLIM Q=0 GAUSSIAN FIT
M     B    (2365.3)    (9.6)          SHAHBAZIA 73 LLIM Q=0
M     C    (2480.0)                   GOYAL     80 XPIM Q=0
M     B    (3568.3)                   SHAHBAZIA 82 LPPI Q=1
M
M     A  K- D TO XI- P K0.
M     B  N P TO LAMBDA LAMBDA X AND PI- P TO LAMBDA LAMBDA X FOR P IN C12.
M     C  GOYAL 80 ALSO SEES A SHOULDER AT 2360 MEV.

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                  108  B=2, S=0 -- WIDTH (MEV)

W     A      (15.0)    (4.0)          BEILLIERE 72 LLIM Q=0 GAUSSIAN FIT
W     B      (47.0)   (15.7)          SHAHBAZIA 73 LLIM Q=0

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Physics Programs with Hyperon Spectrometer

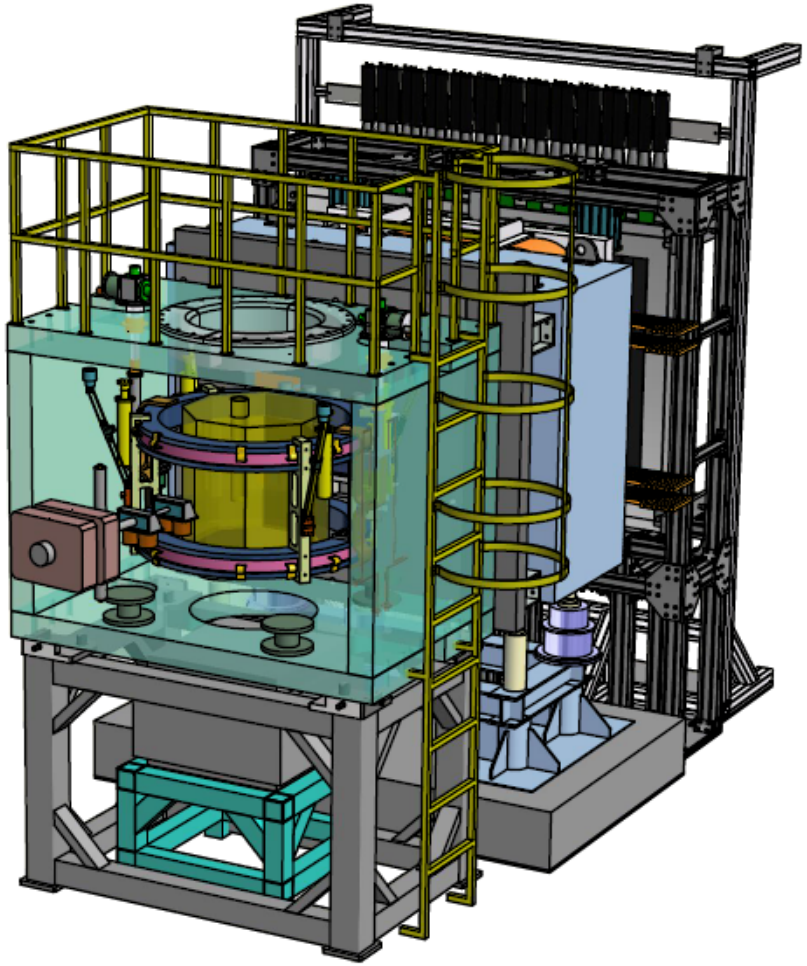
1. H-dibaryon search in $\Lambda p \pi^-$, $\Lambda\Lambda$ and $\Xi^- p$ channels.
2. Cascade weak decays from Ξ-hypernuclei (Charged pions and protons can be reconstructed).
3. $\Xi^- p$ or $\Xi^- {}^{12}\mathrm{C}$ scattering from a laminated target.

- E45 looks for missing baryon resonances in $\pi\pi N$ channels.
- E72 looks for $\Lambda(1665)$ near $\eta\Lambda$ threshold.[11]
- Study of Ξ^* resonances is viable in the $K^- p \to \Lambda K^- K^+$ reaction.

[11] K. Tanida, in Session B2

Summary

- We welcome you to join us on the journey for hunting the H-dibaryon (E42) with the HypTPC at J-PARC.



Schematic view of the E42 setup