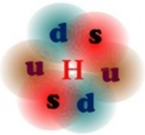
Ken Hicks
Jung Keun Ahn
. . .

Now Pentaquarks, **What's the Next?**
Hexaquark!

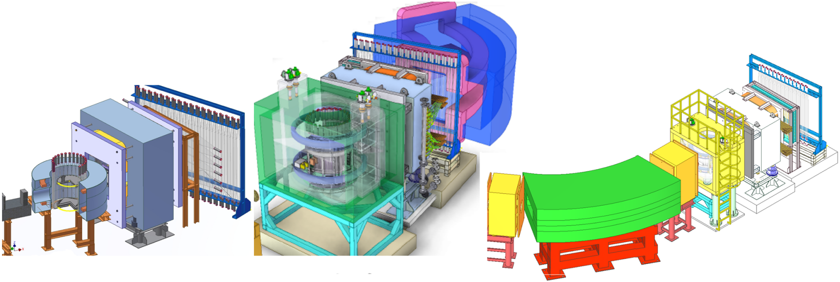


H-Dibaryon Production in the ^{12}C(K^-, K^+) reaction at $p_{K^-} = 1.8$ GeV$/c$

Jung Keun Ahn (Korea University)

Outline

1. Review on the H-Dibaryon Search
2. J-PARC E42 Experiment
3. H-Dibaryon Formation in the (K^-, K^+) Reaction



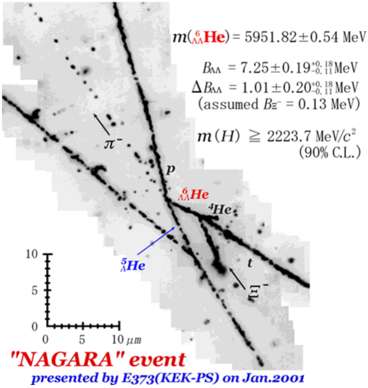
- Progress in last three years since 2012.

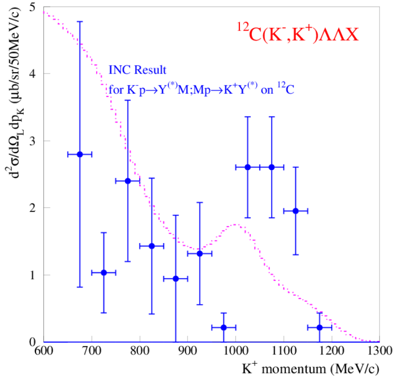
Brief History about the H-Dibaryon Search

40 *Years*!

- Deeply-bound di-hyperon predicted by R. Jaffe (1977).
- No evidence for the deeply-bound H from KEK, BNL, and CERN experimental efforts by more than 80 MeV (1980-2000s).
- Mass constraint from observation of ${}^{6}_{\Lambda\Lambda}$He (E373).
- Enhanced $\Lambda\Lambda$ production near threshold was reported from E224 and E522 at KEK-PS.
- No evidence for $H \to \Lambda p \pi^-$ and $H \to \Lambda\Lambda$ in high-energy e^+e^-, pp and AA collisions from Belle, STAR, and ALICE.

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)

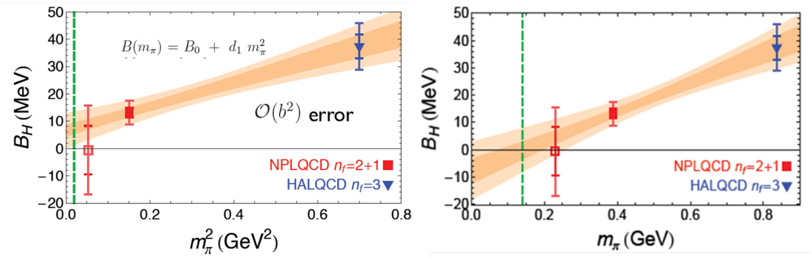
Double-Λ Hypernuclei and Stable H [1]

- Can the H-nuclei and $\Lambda\Lambda$-hypernuclei coexist?
- $\Lambda\Lambda$ bound in the lowest s-orbit of a hypernucleus may be kept apart by a repulsive short-range potential barrier long enough to allow weak decay to compete with H formation.
- Observation of Λ decays in double-Λ hypernuclei does not exclude an H – stable or not – as long as $r_H < 1/3 r_N$.
- If not, the strong decay, for example, ${}^{6}_{\Lambda\Lambda}$He$\rightarrow H\alpha$, should be much more rapid than the weak decay.

[1] G.R. Farrar and G. Zaharijas, *arXiv:hep-ph/0303047*

H-Dibaryon from Lattice QCD[2]

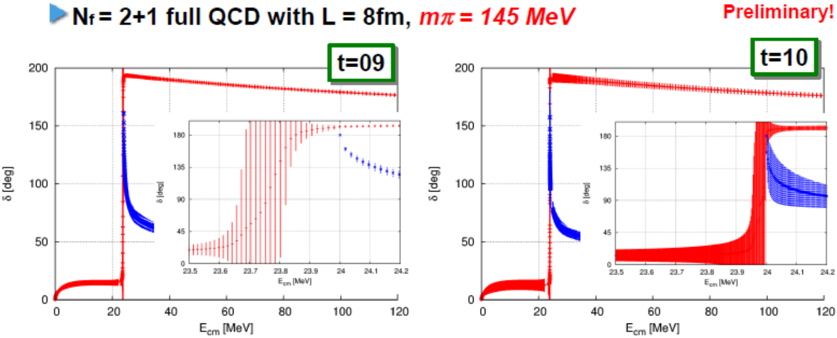
- Recent LQCD calculations seem to point to a weekly bound H or resonant state although we have got to wait for definite results with physical quark masses.



[2] HAL Collab., PRL 106 (2011)/ NPLQCD Collab. PRL 106 (2011)/ Shanahan, Thomas, Young, PRL 107 (2011)

H-Dibaryon from Lattice QCD[3]

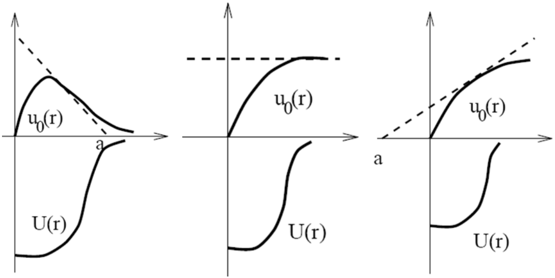
- $\Lambda\Lambda$ and $N\Xi$ $(I = 0)$ $^1S_0$ Phase Shifts



[3] K. Sasaki for the HAL Collab., HYP2015 (2015)

Bound, Virtual State ($a_{\Lambda\Lambda} = \infty$), or Resonance?

- 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

H-Dibaryon Search at J-PARC : E42

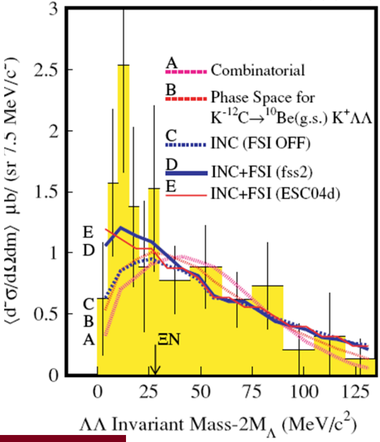
The J-PARC-E42 experiment searches for the H-dibaryon

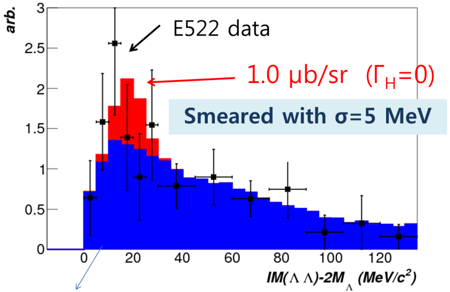
1. in $\Sigma^- p,\ \Lambda p \pi^-,\ \Lambda\Lambda$ and $\Xi^- p$ channels
2. by tagging the $S = -2$ system production
3. via (K^-, K^+) reactions at 1.8 GeV$/c$ with a diamond target.

H-Dibaryon Search at J-PARC : E42

4 Hyperon Spectrometer : 1 MeV ΛΛ mass resolution!

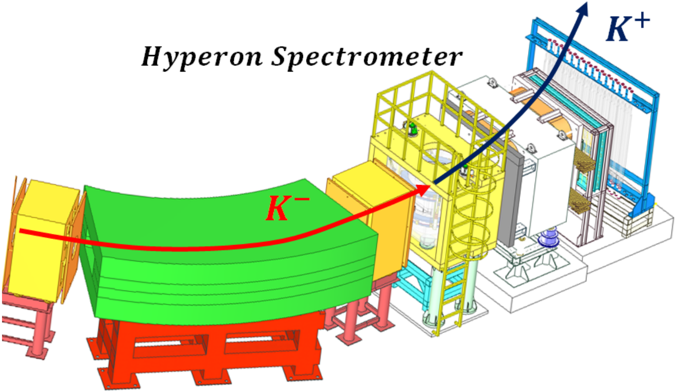
PHYSICAL REVIEW C 75, 022201(R) (2007)





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

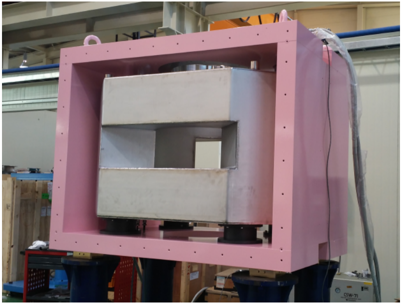
Hyperon Spectrometer

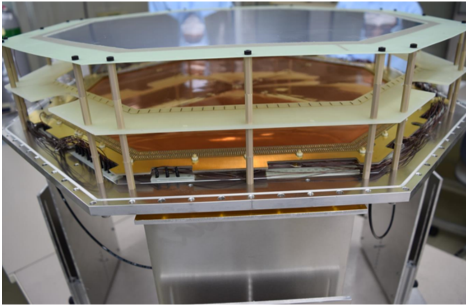


- The Hyperon spectrometer consisting of a time projection chamber (HypTPC) in the superconducting dipole magnet will be placed between the K1.8 beam spectrometer and the forward KURAMA spectrometer.

Superconducting Magnet and TPC

- The conduction-cooled superconducting magnet and the time projection chamber will be soon ready.



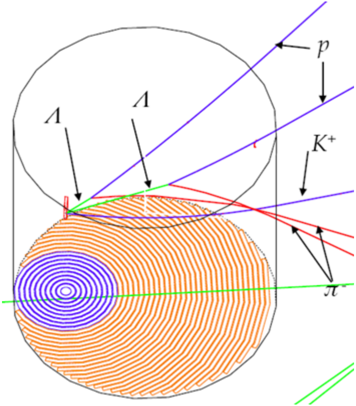


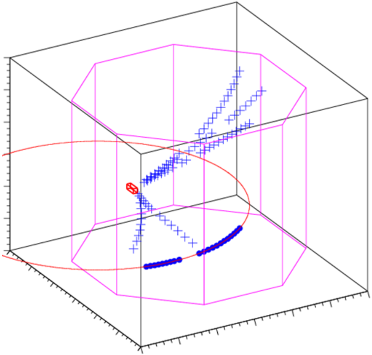
Yield Estimate

Parameters	Proposal	New Values
K^- beam	$10^6 K^-$/ spill (6 s)	$6 \times 10^5 K^-$/ spill (5.5 s)
Target length	15 mm	20 mm
Number of nuclei	2.65×10^{23}/cm^2	
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr	
$\Delta\Omega(K^+)$	0.11 sr	0.16 sr
Br$(\Lambda \to p\pi^-)^2$	0.41	
K^+ Reconstruction	0.5	
$\Lambda\Lambda$ Reconstruction	0.4-0.6	
Yield	0.023 event / spill	0.03 event / spill

- Diamond ^{12}C target.
- 15000 $\Lambda\Lambda$ events for 100 shifts at the current beam power.

A Full Simulation on the Hyperon Spectrometer

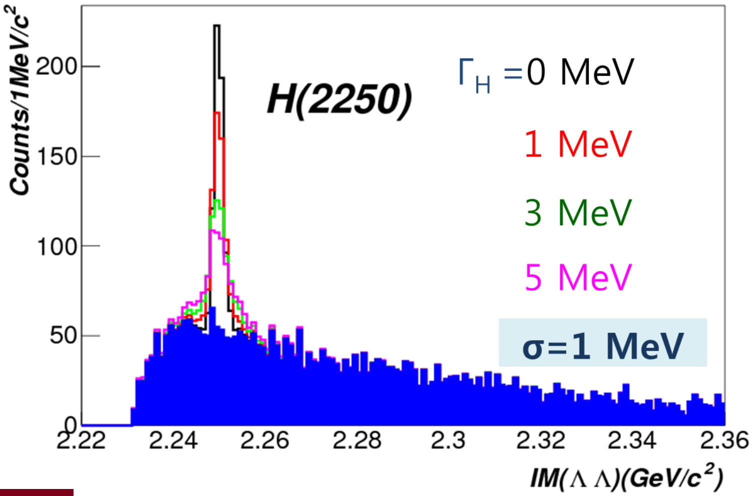




- A full Geant4 simulation on the response of the HypTPC.

Simulated $\Lambda\Lambda$ Spectrum from E42

- Lineshapes with respect to Γ_H (assuming $\sigma_m = 1$ MeV).



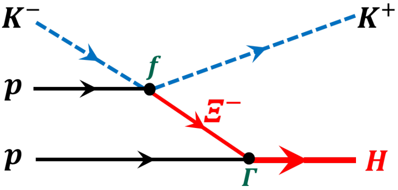
H Production from (K^-, K^+) Reactions[4] [5]

- Lowest-order process for H production on a diproton pair

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

- The decay vertex amplitude Γ describes the fusion of $\Xi^- p$ systems into a six quark state H of radius R:

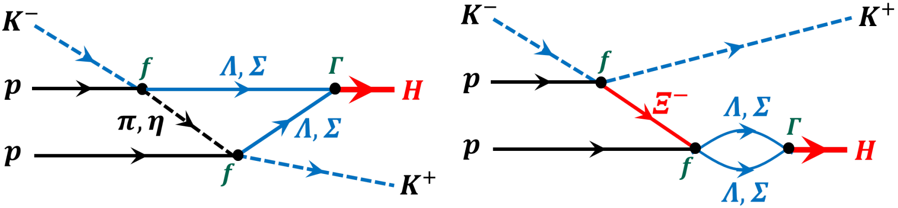
$$\Gamma = \Gamma_0 e^{-\frac{R}{12}(\vec{p}_p - \vec{p}_\Xi)^2}$$



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

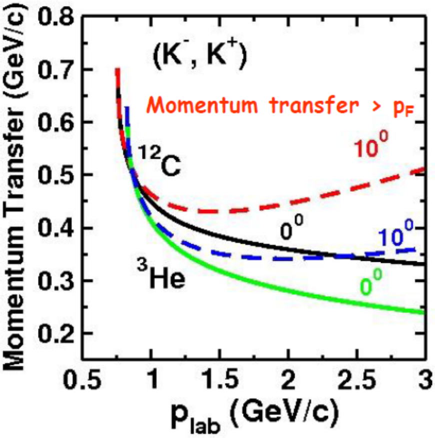
Higher-order H Production Processes [6]

- Higher-order processes for H production on a diproton in the (K^-, K^+) reaction:

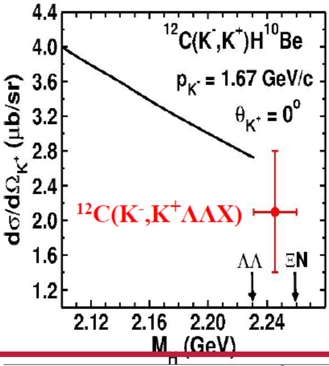


[6] A.T.M. Aerts and C.B. Dover, Phys. Rev. D28, 450 (1983)

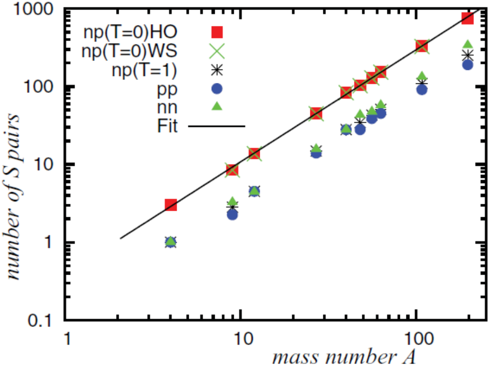
Momentum Transfer in the (K^-, K^+) Reeaction [7]



- The momentum transfer $q \geq 366$ MeV/c (at $p_{K^-} = 1.8$ GeV/c) always remains larger than the Fermi momentum $p_F = 250$ MeV/c.



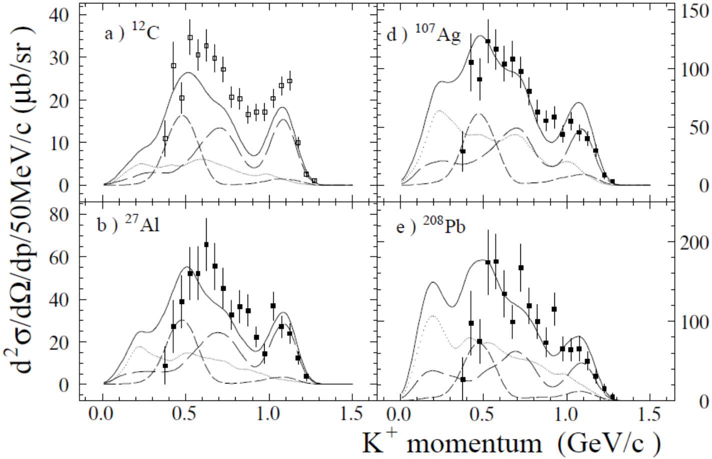
Correlated Pairs in Nuclei [8]



- The number of pp, nn, and np pairs with $L = 0$.
- A high-momentum nucleon should be balanced by one other nucleon with large relative momentum and small total momentum.
- Short-range correlated pairs apart by $\sim$ 1.0 fm (1.7 fm on average for nucleons.)
- Measurement of ^{2}He (pp resonance) production in the ^{12}C(p, p') reaction at $p = 390$ MeV is helpful?

[8] M. Vanhalst, W. Cosyn and J. Ryckebusch, Phys. Rev. C84, 031302(R) (2011)

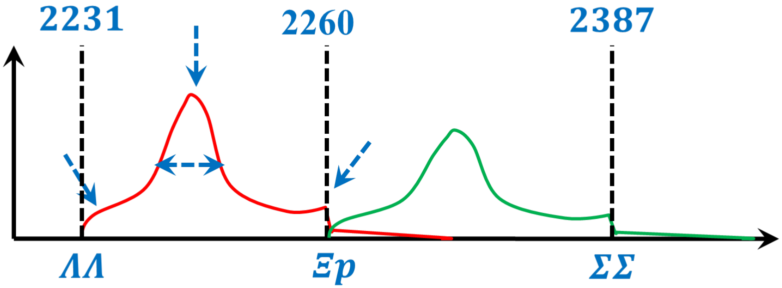
Intranuclear Cascade Model Calculation[9]



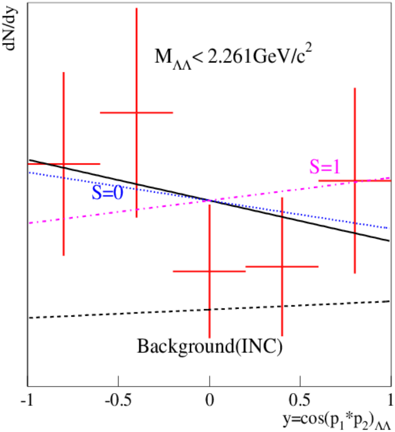
[9] Y. Nara, A. Ohnishi, T. Harada and A. Engel, Nucl. Phys. A614, 433 (1997)

Lineshape Analysis

- Detailed lineshape analysis is possible due to 1-MeV mass resolution.
- Asymmetric or distorted lineshapes, or cusp in the mass spectrum!



Spin Analysis



- Spin composition measurement from E224:

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

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

where θ^* is the angle between the two decay protons in the $\Lambda\Lambda$ rest frame.

Other Physics Opportunities

- The Hyperon Spectrometer is also utilized for the E45 experiment, where baryon resonances are studied in $\pi p \to \pi\pi N$ reactions.
- Radiative $\Lambda(1405)$ decay measurement could provide a new insight on the nature of $\Lambda(1405)$.
- The $K^- pp$ nuclear system can also be studied with the $\pi^+ d \to K^+(K^- pp)$ reaction.
- The HypTPC is also utilized to measure X-rays from Ξ^- capture in ^{12}C.
- $\Xi(1690)^-$ in $K^- p \to K^+ K^- \Lambda$.
- $f(1280)$ decaying into $K^* \overline{K}$ in $K^- p \to K^+ K^- \pi \Lambda$.
- Missing nucleon resonances decaying into $K^+ \Lambda$ in $K^- p \to K^+ K^- \Lambda$.