Search for H-Dibaryon with a Large Acceptance Hyperon Spectrometer

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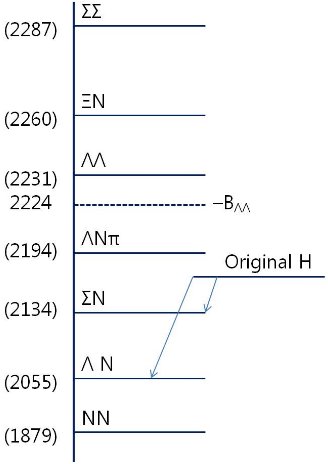
Contents

H-Dibaryon

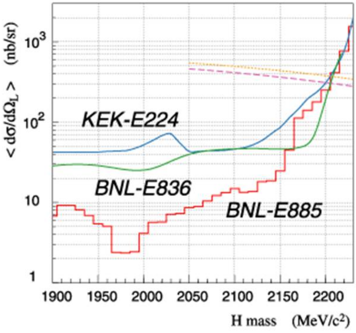
- A stable $SU(3)_f$ singlet 6-quark (uuddss) state due to QCD color magnetic force.
- It has not been unambiguously observed experimentally.
- The observation of several double-Λ hypernuclear events (${}^{6}_{\Lambda\Lambda}$He, ${}^{10}_{\Lambda\Lambda}$Be*, ${}^{11}_{\Lambda\Lambda}$Be, ${}^{13}_{\Lambda\Lambda}$B) in nuclear emulsion suggests that the H-dibaryon is very loosely bound ($<$ 7 MeV) or unbound relative to $2m_\Lambda$.

H-Dibaryon Mass Hierarchy



- For $m_{\Sigma N} < m_H < m_{\Lambda N\pi}$, the H decays via $\Delta S = 1$ weak process. Due to the Pauli principle, ΣN final state is preferred over Λn.
- The more conventional nonleptonic decay involving pion, $H \to \Lambda N\pi$, is allowed if $m_H > 2.194$ GeV.
- For $m_H < 2m_\Lambda$, the H-dibaryon could appear as a threshold enhancement in $\Lambda\Lambda$ scattering (like the NN-isosinglet).

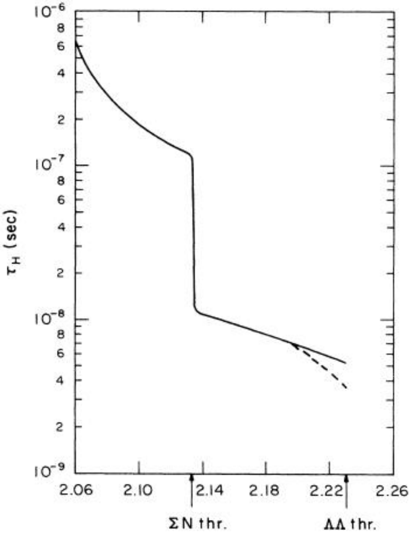
Upper Limits on H Production in (K^-, K^+) *Reaction*



- Upper limits on the H-production at 90% CL in terms of the H-mass reported by KEK-E224, BNL-E836, and BNL-E885.
- Dashed and dotted-dashed lines indicate theoretical estimates by Aerts and Dover for ^{12}C with different choices for elementary $p(K^-, K^+)\Xi^-$ cross section.

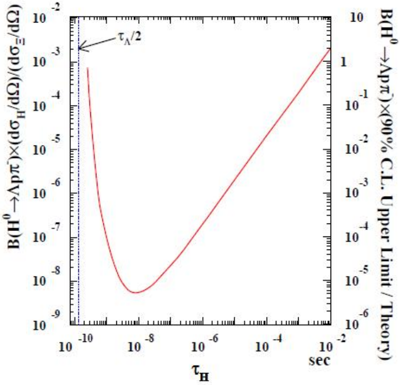
- Note that the previous experiments give no conclusive results to rule out the theoretical estimates above 2210 MeV, because of a large tail of the Ξ^- production and other processes.

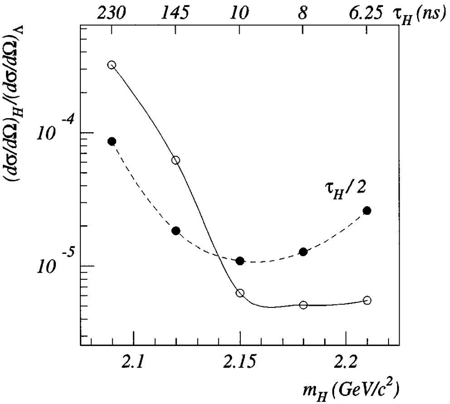
Lifetime of the H



- Donoghue *et al.* predicted the lifetime of the H in terms of its mass. Dashed line indicates the $H \to \Lambda N \pi$ decay (Phys. Rev. D34 (1986) 3434).
- The H lifetime is estimated to be about 2×10^{-9} s close to $\Lambda\Lambda$ threshold, which is an order of magnitude longer than Λ's lifetime.

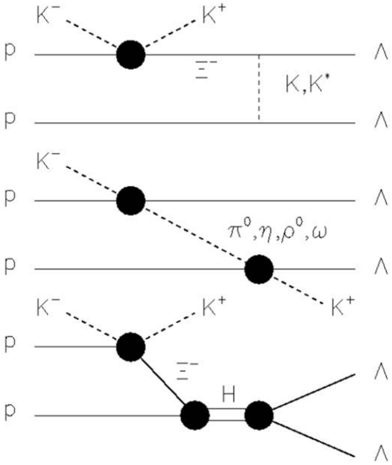
Upper Limits on H Production in $p + A$ Interactions





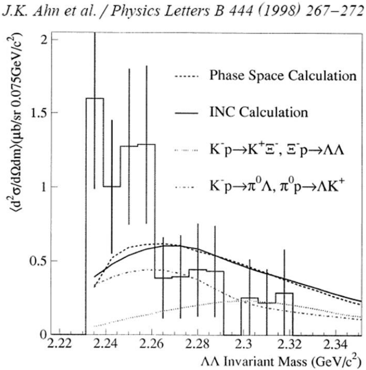
- Upper limits on H production cross sections from KTeV (left) and BNL-E888 (right).
- Both have searched for rather long-lived H compared to Λ.

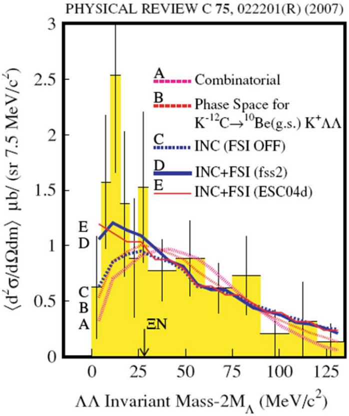
$\Lambda\Lambda$ *Production in* (K^-, K^+) *Reaction*



- Ξ^- interacts with a proton in the same nucleus to produce $\Lambda\Lambda$.
- Λ is produced with an intermediate meson in K^-p reaction and then the meson interacts with a proton in the same nucleus to produce the other Λ and K^+.
- Ξ^-p fuses to H which decays into $\Lambda\Lambda$.

H-Dibaryon as a $\Lambda\Lambda$ *Resonance?*





- Threshold enhancement in $\Lambda\Lambda$ is indicative of either a virtual state or a bound state or a resonance.

Recent Lattice QCD Results

- Most recently, two independent and different LQCD calculations have found evidence of a bound or weakly-bound H-dibaryon.

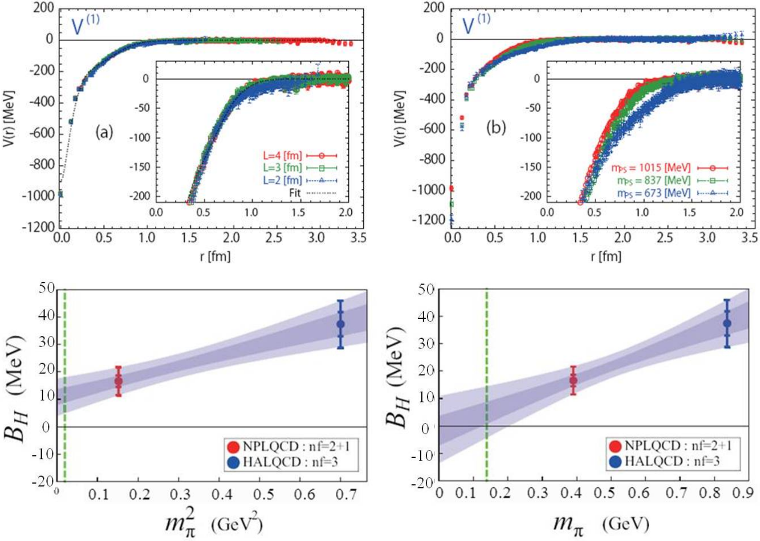
HAL collaboration

The HAL collaboration studies the effective potential in s-wave dibaryon channel in the SU(3) limit and predicts the H to be bound by $35.6 \pm 7.4 \pm 4.0$ MeV at the pion mass of 673 MeV (Phys. Rev. Lett. **106**, 162002 (2011)).

NPLQCD collaboration

The NPLQCD collaboration performs Luscher's finite-volume method without SU(3) symmetry and finds the H to be bound by $16.6 \pm 2.1 \pm 4.5$ MeV at the pion mass of 389 MeV (Phys. Rev. Lett. **106**, 162001 (2011)).

Lattice QCD Results



Bound, Virtual State or Resonance?

- The quark model calculations of the H-mass indicate an attractive QCD force in the singlet channel, but they are much less conclusive on whether it results in a bound state, a virtual state, or a resonance.
- It could show up as a virtual state ($a_{\Lambda\Lambda} = \infty$) in the S-wave $\Lambda\Lambda$ system, not as a resonance.
- Anomalously large scattering length (like the NN-isotriplet) leading to a threshold enhancement in the $\Lambda\Lambda$ spectrum near threshold.
- The enhancement could be a sign of a bound state just below threshold (like the NN-isosinglet, where the deuteron lies).
- Weak decay, Threshold enhancement, or Breit-Wigner peak.

H-Dibaryon Search at J-PARC

Goals

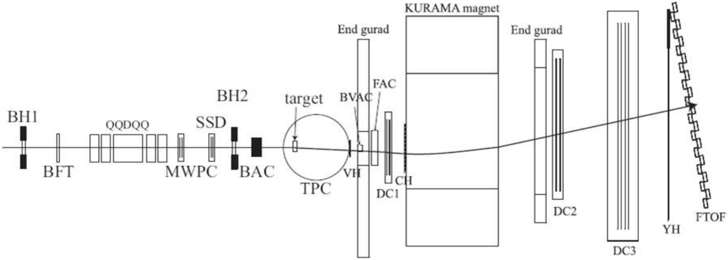
1. To confirm if the previously observed enhancement near the $\Lambda\Lambda$ threshold is indeed due to the existence of the H-dibaryon based on much higher statistics.
2. To provide more stringent upper limit for the H-dibaryon production.

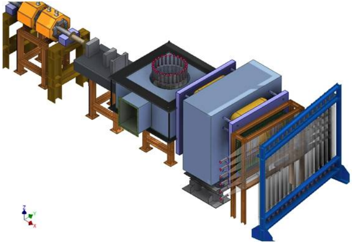
Features

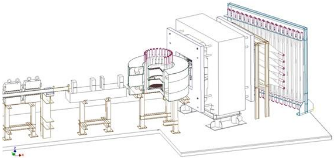
- (K^-, K^+) reaction on a Cu target at $p_{K^-} = 1.8$ GeV$/c$.
- Large acceptance for $\Lambda\Lambda$ detection near the target (a Helmholtz-type dipole magnet with a TPC and trigger counters).

Experimental Setup

- Hyperon Spectrometer + K^+ Spectrometer

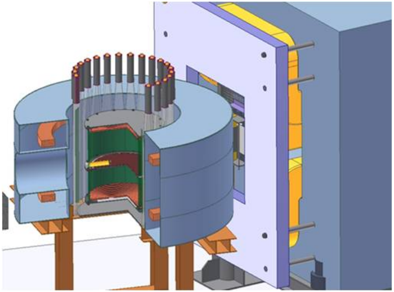


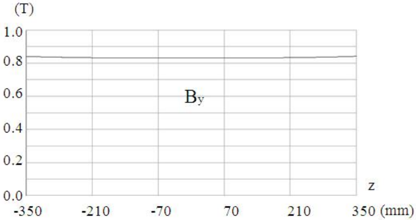




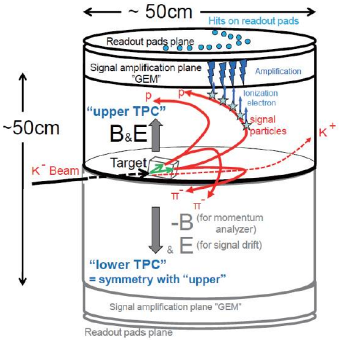
Large-Acceptance Hyperon Spectrometer with TPC

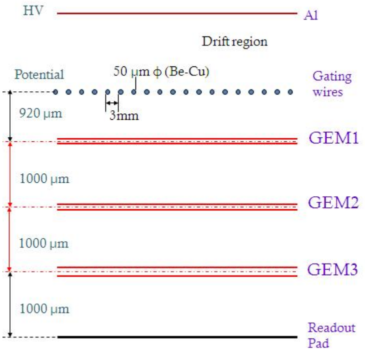
- A superconducting Helmholtz-type magnet with a Time Projection Chamber (HypTPC).
- 1 T magnetic field is uniform within 5% over a TPC drift volume of 50 cm in diameter and 50 cm in length.





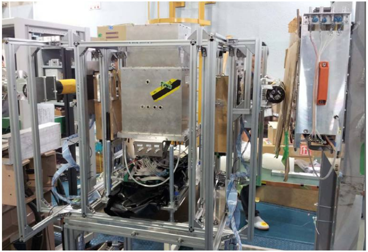
Time Projection Chamber (TPC)

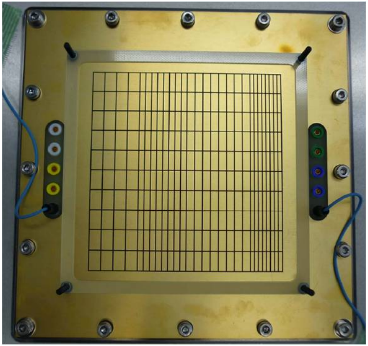




- Cylindrical configuration to fit with the inner structure of the magnet. The signals are amplified by 3 layers of GEM and are read with anode pads at both ends of the TPC.

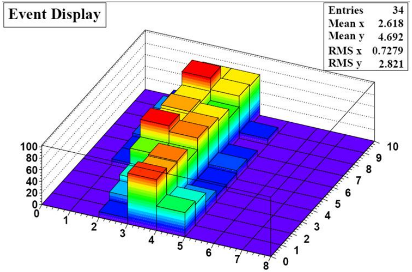
Test Experiment (RCNP-E384)

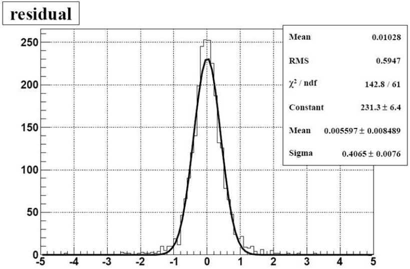




- A $10 \times 10 \times 20$ cm^3 prototype TPC was constructed at JAEA. The signals were read out through preamp-shaper and 40 MHz flash ADC.
- A test measurement of the prototype TPC using a 400-MeV proton beam up to 10^7 Hz at RCNP, Osaka University.

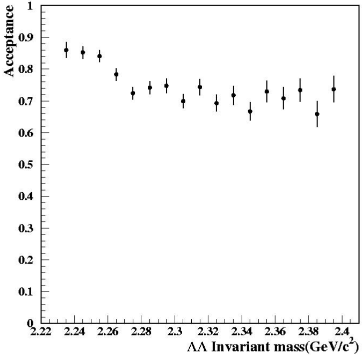
Performance of the Prototype TPC

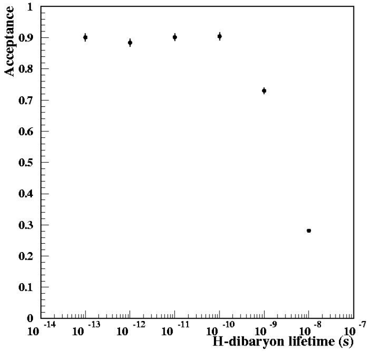




- A typical pulse-height distribution of the TPC exposed to 400 MeV protons at 10^6 Hz (left).
- The rms value of the track residual distribution was estimated to be 400 μm (right).

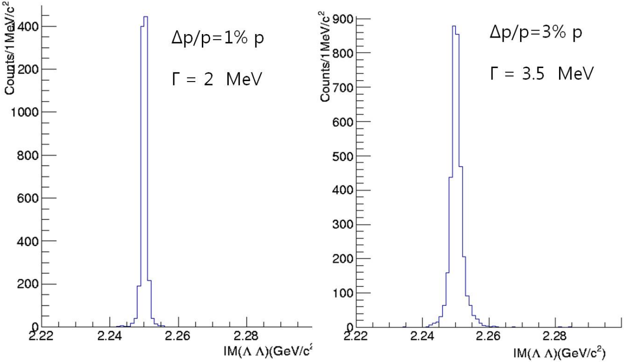
Sensitivity to Mass and Lifetime





- The detection efficiency was estimated to reach almost 0.9 by requiring that a particle should pass more than 8 pad layers.
- Good sensitivity to the whole mass region of our interest for the H above $\Lambda\Lambda$ threshold, and to the lifetime shorter than 10^{-9} s for the $H \to \Lambda p \pi^-$ decay.

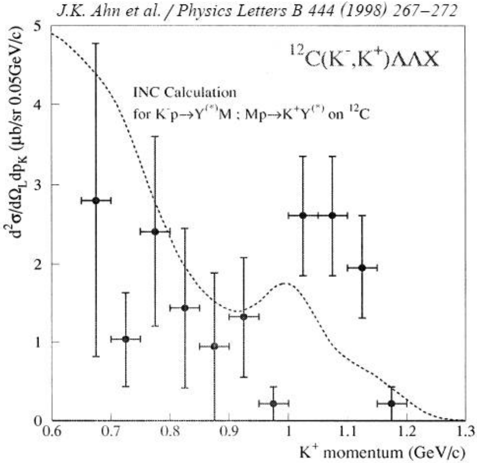
Mass Resolution



- With a position resolution of 300 μm, the pion momentum resolution of about 1% is expected at 300 MeV/c.
- $\Lambda\Lambda$ mass resolutions ($\Gamma = 2$ MeV for $\Delta p/p =$1% $\cdot p$ and $\Gamma = 3.5$ MeV for $\Delta p/p =$3% $\cdot p$)

The H Production Cross Section?

- Theoretical prediction by Aerts and Dover for $K^-(pp) \rightarrow K^+H$ on ^{3}He ($\sim 0.2\mu$b/sr)
- KEK-E224 measurement for ^{12}C$(K^-, K^+)\Lambda\Lambda$X (7.6μb/sr and 1μb/sr for the H).

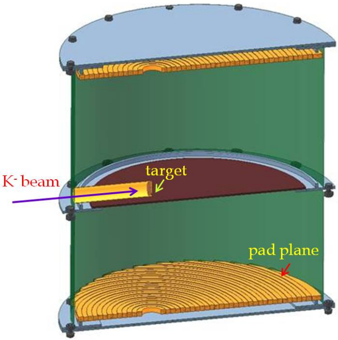


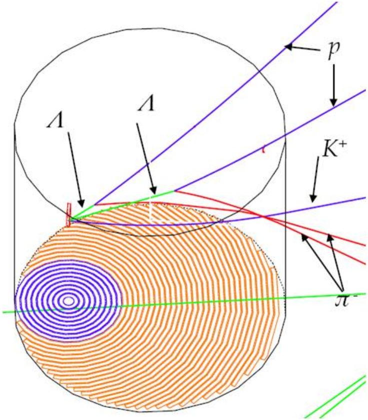
Yield Estimate

Parameters	Values
K^- beam	$10^6 K^-$ per spill (6 s)
Cu target	4.25×10^{22} protons
$d\sigma/d\Omega_L^{Cu}(\Lambda\Lambda)$	14.6μb/sr
$\Delta\Omega$	0.11 sr
Branching ratio $(\Lambda \to p\pi^-)$	0.64
Detection efficiency of K^+ with Kurama	0.5
Detection efficiency of two Λs with TPC	0.5
Yield	0.007 event / spill

- The TPC detection efficiency was set to 0.5 (instead of 0.9) for a conservative estimate.
- 3300 $\Lambda\Lambda$ for 100 shifts and 200 H(2250) events for 1.0 μb/sr. If the H-dibaryon cross section is 0.2 μb/sr as predicted for ^{3}He, about 50 H events are expected. (For the Cu target, much more events are expected.)

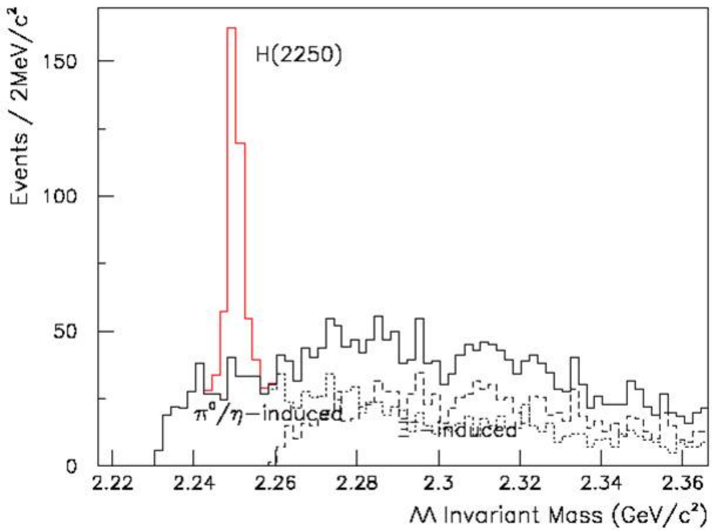
TPC Configuration and Simulated ΛΛ Events



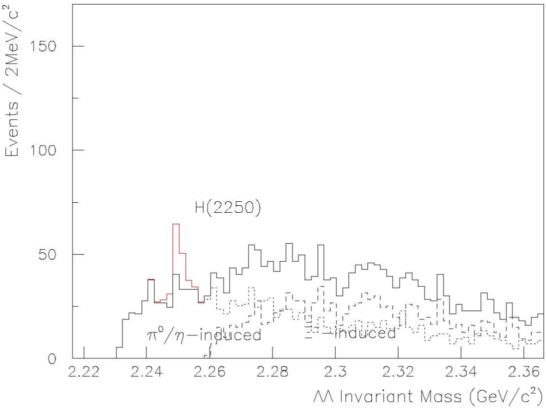


- Two pad planes share one HV plane with each other.
- For each plane, 6000 pads in 10 to 38 pad layers with 10 mm pad length and 3 mm spacing.

H(2250) Resonance for 1 $\mu b/sr$

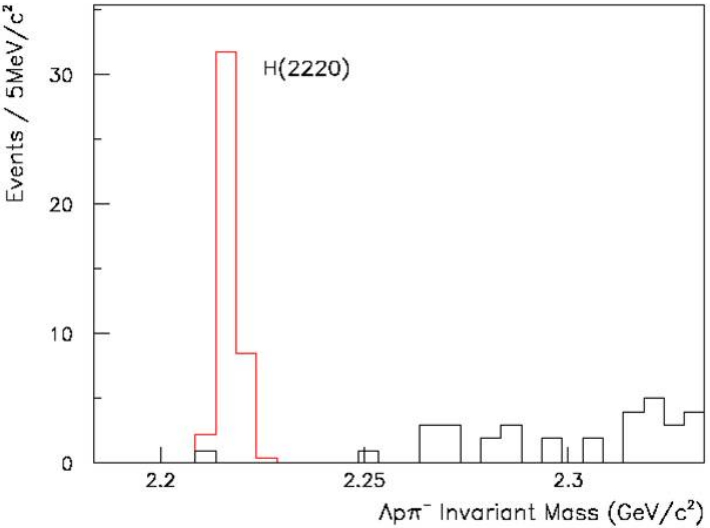


H(2250) Resonance for 0.2 $\mu b/sr$



- Note that the H-production cross section (0.2 μb/sr) for ^{3}He is assumed, while background processes were calculated for ^{63}Cu.

Weakly-bound H(2220) in $\Lambda p \pi^-$ Mass



Summary

- Recent LQCD calculations seem to point to a weakly-bound H or a resonance although we have got to wait for definite results with physical quark masses.
- We propose to search for the H-dibaryon resonance in $\Lambda\Lambda$ system and the bound one decaying weakly to $\Lambda p \pi^-$ or $\Sigma^- p$ system at J-PARC.
- If the H-dibaryon lies just below $\Lambda\Lambda$ threshold as either of a virtual state or a weekly-bound state, a threshold enhancement in $\Lambda\Lambda$ system can be measured as well as a possible direct search for its weak decays in the hyperon lifetime range.
- We plan to construct a hyperon spectrometer with a TPC to track Λ decays.
- We expect to collect 3300 $\Lambda\Lambda$ events for 100 shifts.