14th International Conference on Hypernuclear and Strange Particle Physics - HYP2022, June 30, 2022

Current performance and future upgrades of Hyperon Spectrometer for exotic hadron search experiments at J-PARC

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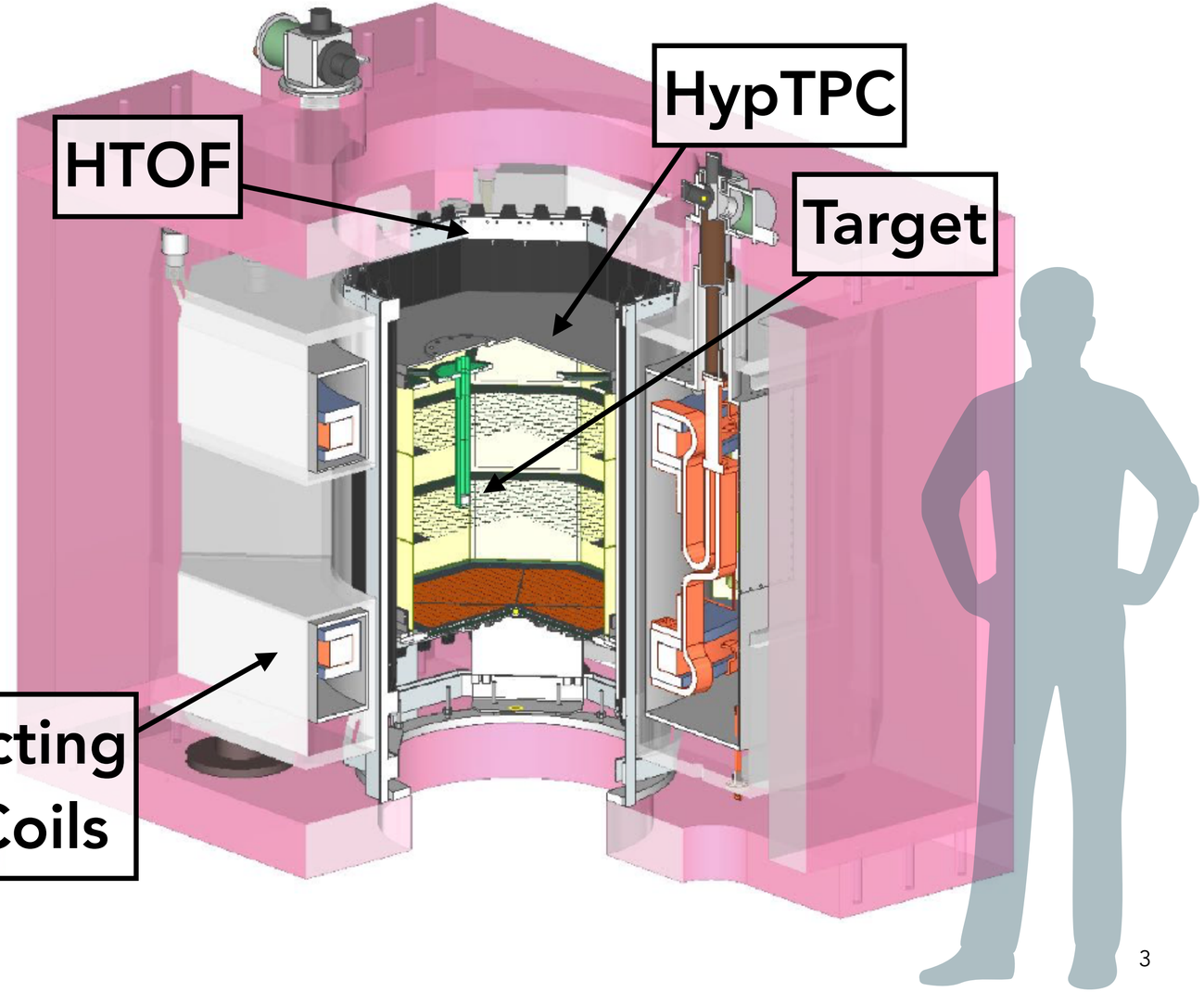
Hyperon Spectrometer

Hyperon Spectrometer

Measure invariant mass of decay particles and identify final state

consists of

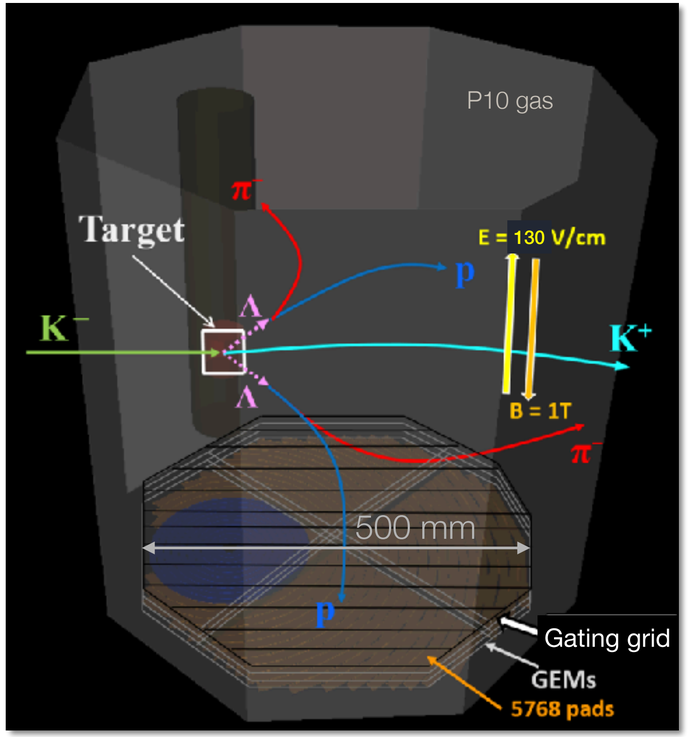
- **Helmholtz coil type superconducting magnet**
- **3D tracking detector, HypTPC**
- **Time-of-flight detector, HTOF**



HypTPC/HTOF

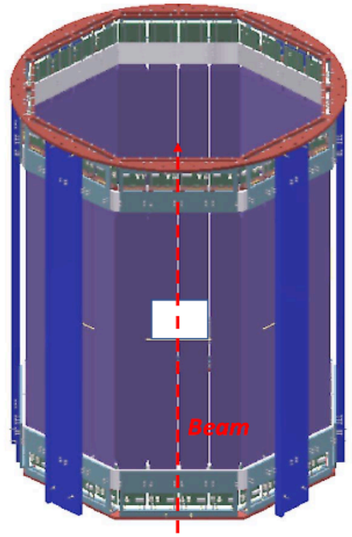
Time Projection Chamber (TPC)

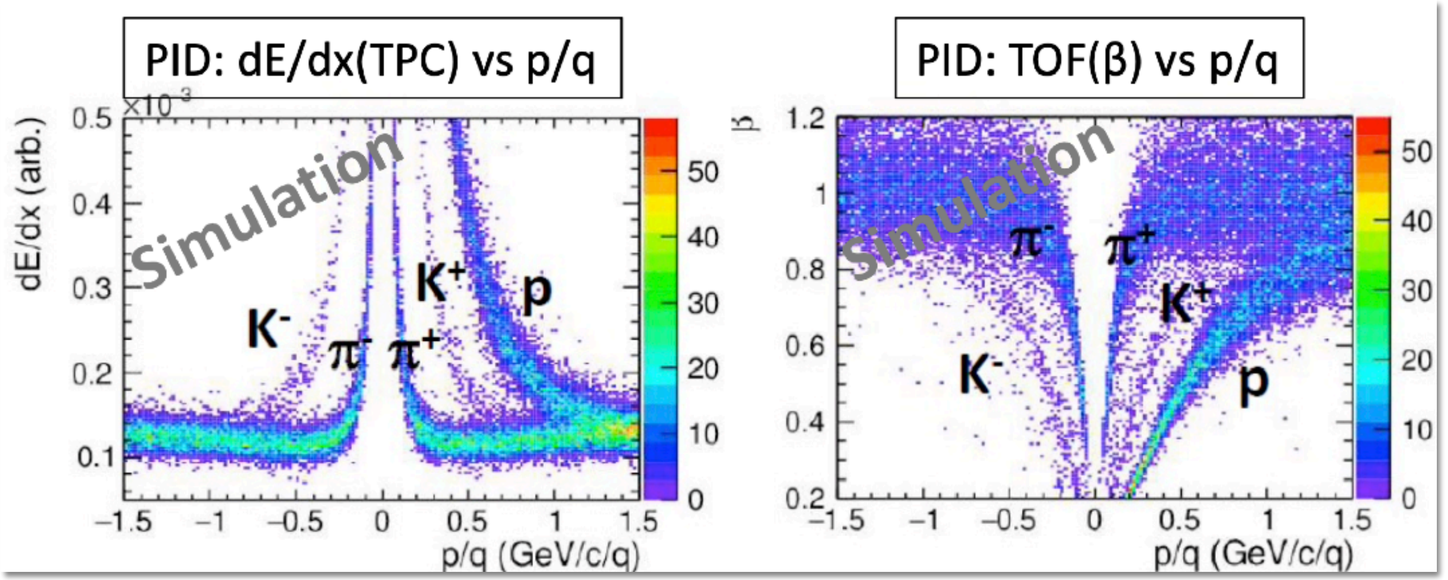
- Large acceptance by built-in target
- Position resolution < 300 μm
- Momentum resolution : 1–3% for π/p



HTOF

- Time resolution < 150 ps
- PID with HypTPC
- Charged particle number



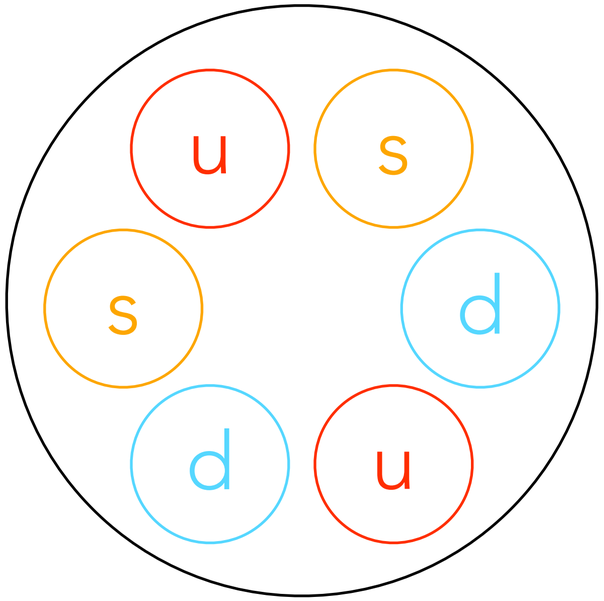


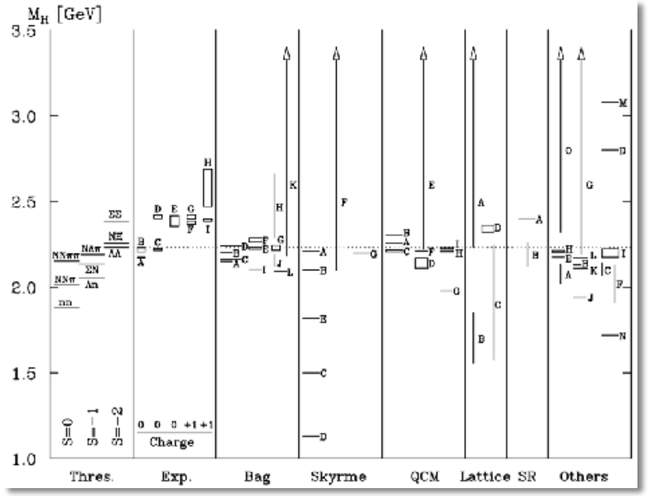
H-dibaryon search experiment, J-PARC E42

H-dibaryon

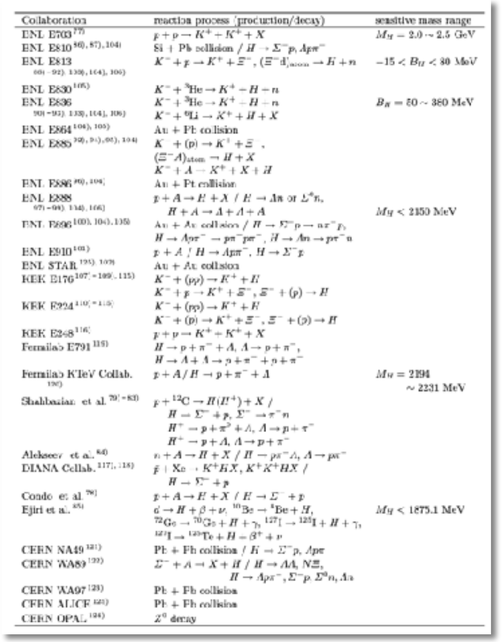
uuddss, $SU_f(3)$ singlet 6-quark state, $I = J = Y = 0$

- Predicted by R.L. Jaffe: $M_H = 2M_\Lambda - 81\ \mathrm{MeV}$, PRL 38, 195 (1977).
- Since then, many theoretical calculations and search experiments have been performed, but still unconfirmed.



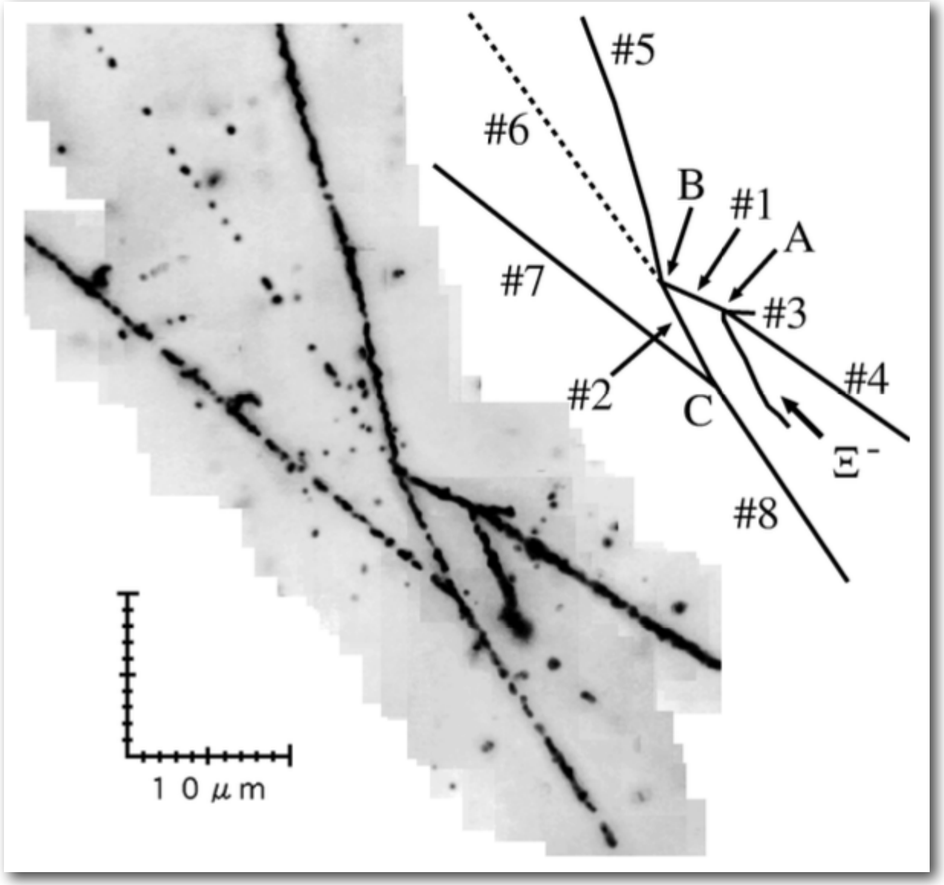


PTPS 137, 121 (2000)



Double Λ hypernucleus, NAGARA event

Double Λ hyper nuclei have been found by emulsion experiments, and H nuclei cannot be lighter than that at least.



PRL 87, 212502 (2001)

$$B_{\Lambda\Lambda} \equiv M({}^{A-2}Z) + 2M_\Lambda - M({}^{A}_{\Lambda\Lambda}Z)$$

$$M_H > 2M_\Lambda - B_{\Lambda\Lambda}$$

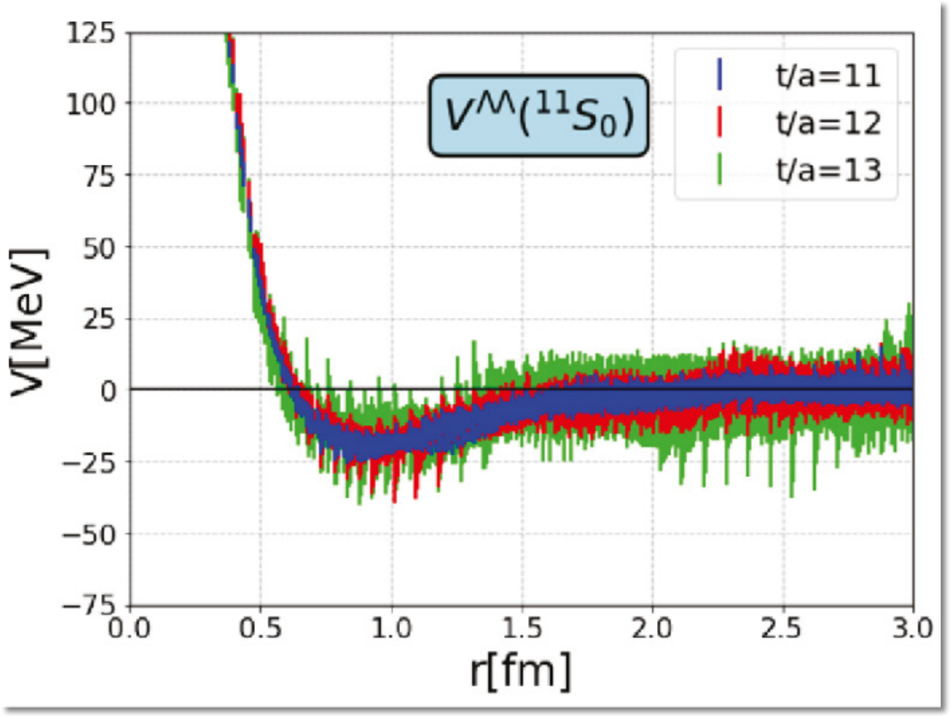
$$\underline{7 \text{ MeV}}$$

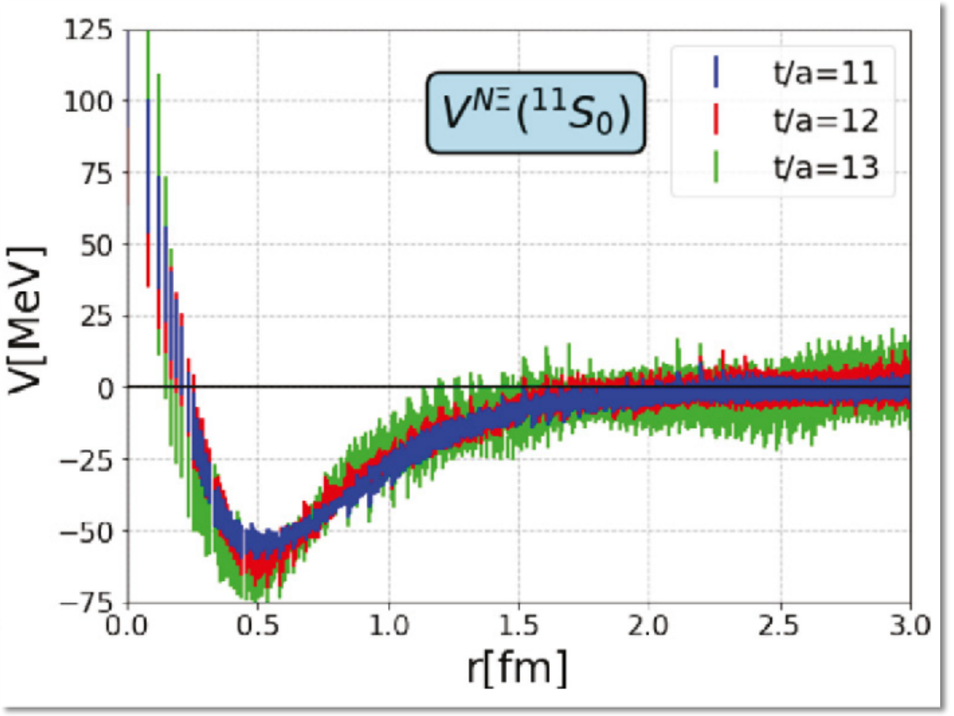
H mass is limited.

Recent HALQCD calculation

New calculations on the interaction between $\Lambda\Lambda$ and ΞN in S waves

Nucl. Phys. A 998, 121737 (2020)



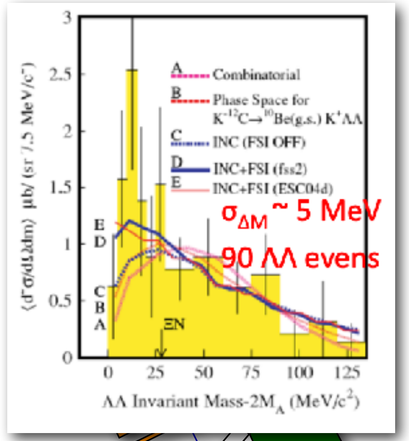


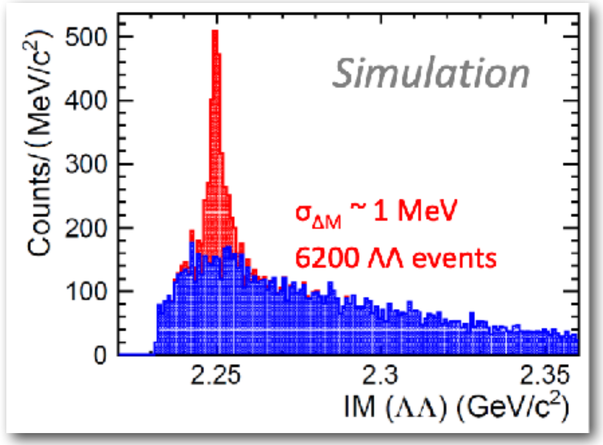
The attraction of $\Lambda\Lambda$ is weak and ΞN is strong.

H is closer to the ΞN threshold than near the $\Lambda\Lambda$ threshold if it exists.

J-PARC E42 experiment

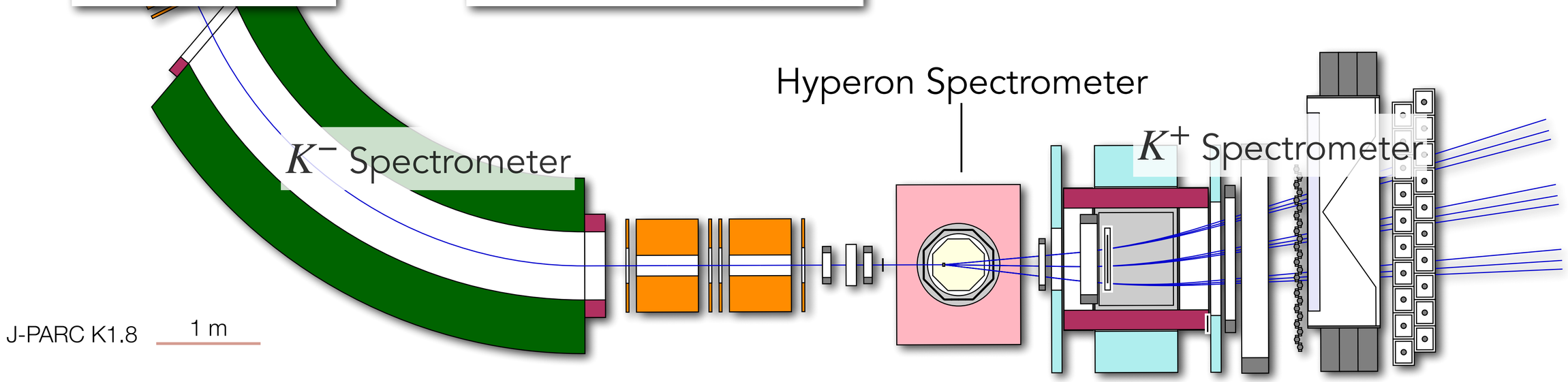
H dibaryon search experiment via $^{12}\mathrm{C}(K^-, K^+)$ reaction at $p_{K^-} = 1.8$ GeV/c





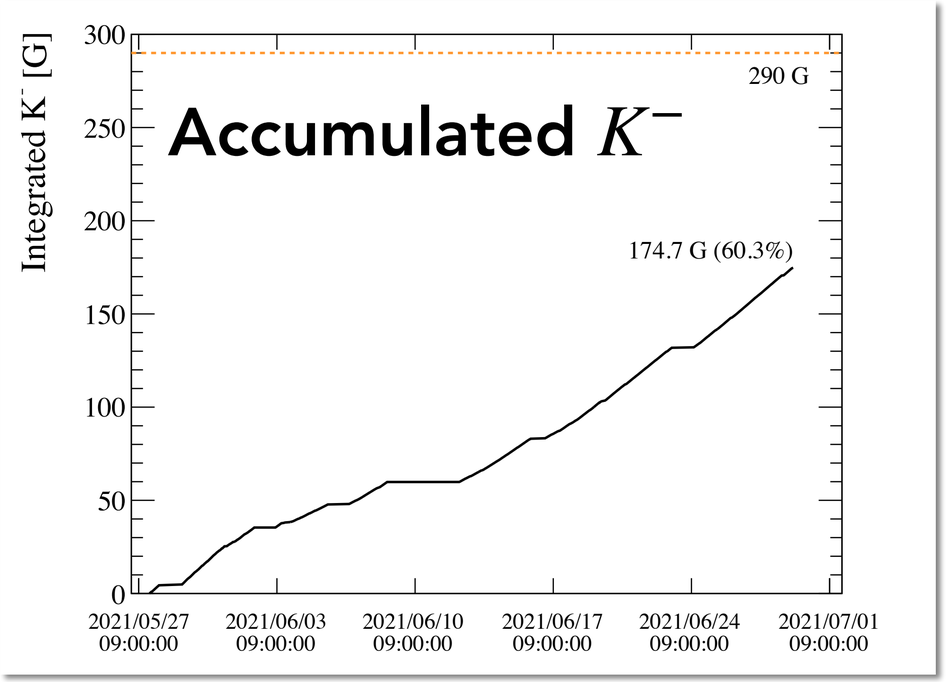
Upgraded previous study to higher resolution and statistics

Sensitivity to a wide mass range of $\Lambda p\pi^-$, $\Lambda\Lambda$, $\Xi^- p$

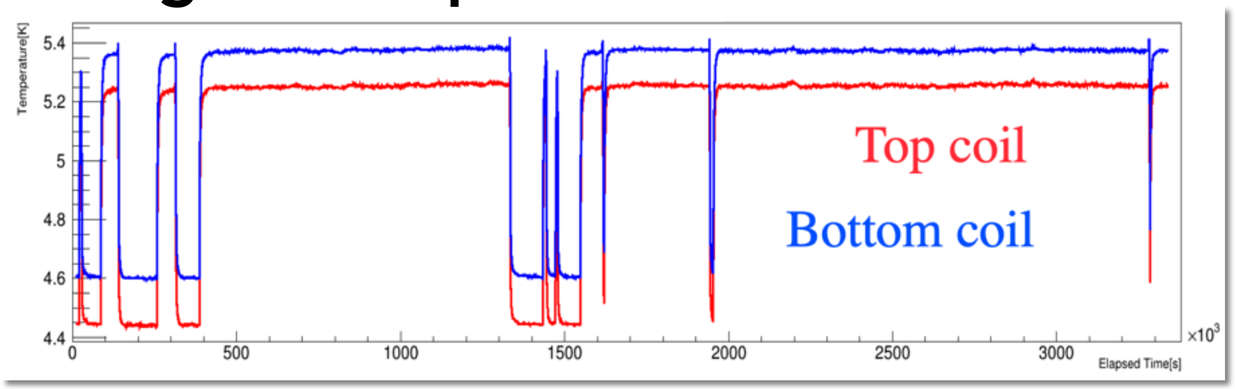


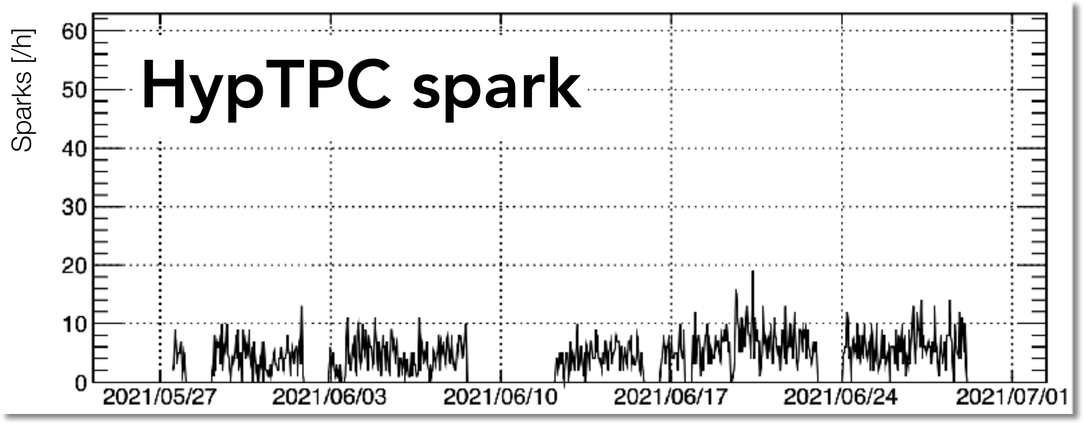
J-PARC E42 Run

- **22.7 days** of physics data in May and June 2021
- Total beam count : **1.75×10¹¹** K^-
- Long-term stable operation of superconducting magnet and HypTPC up to **350 kHz** beam.

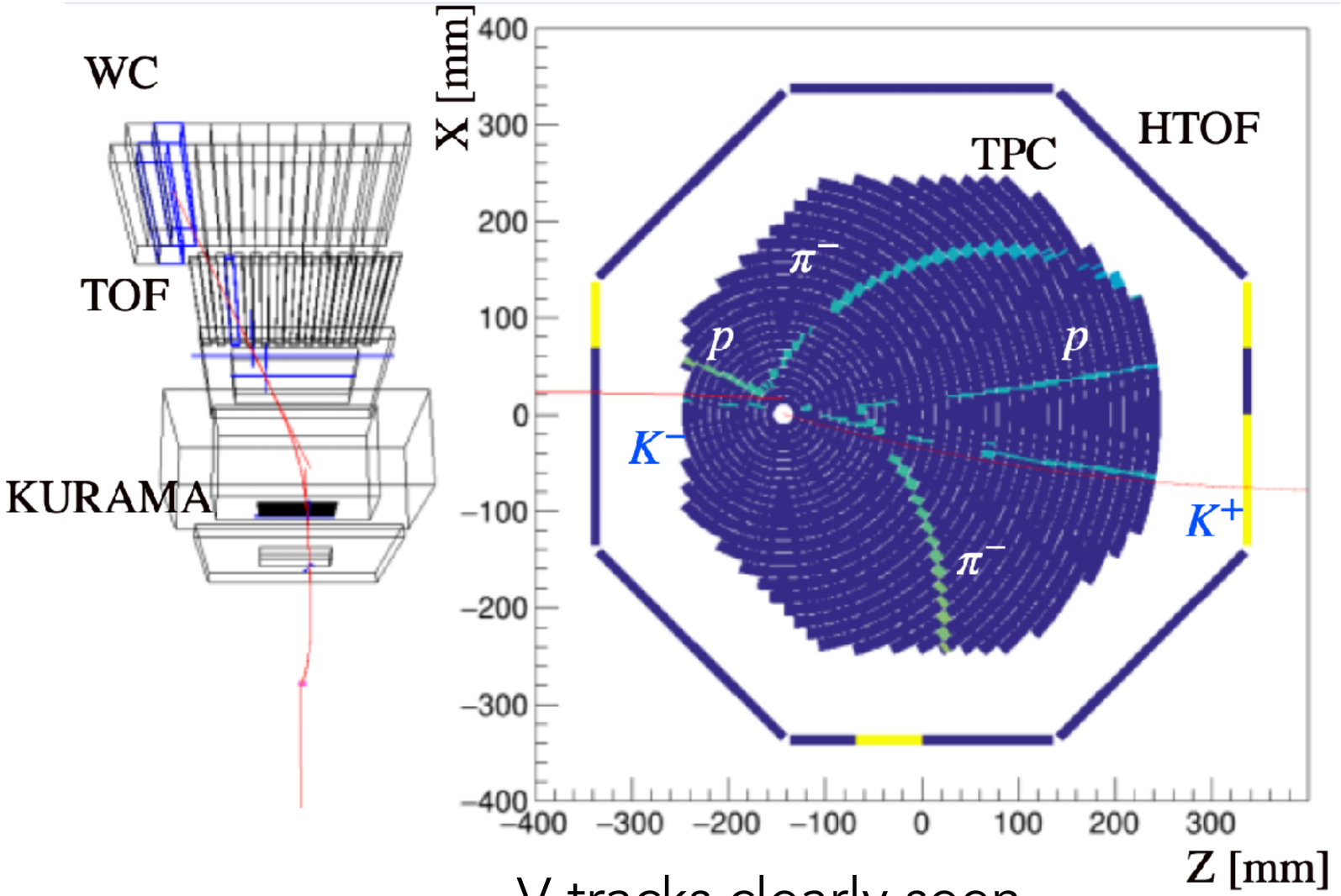


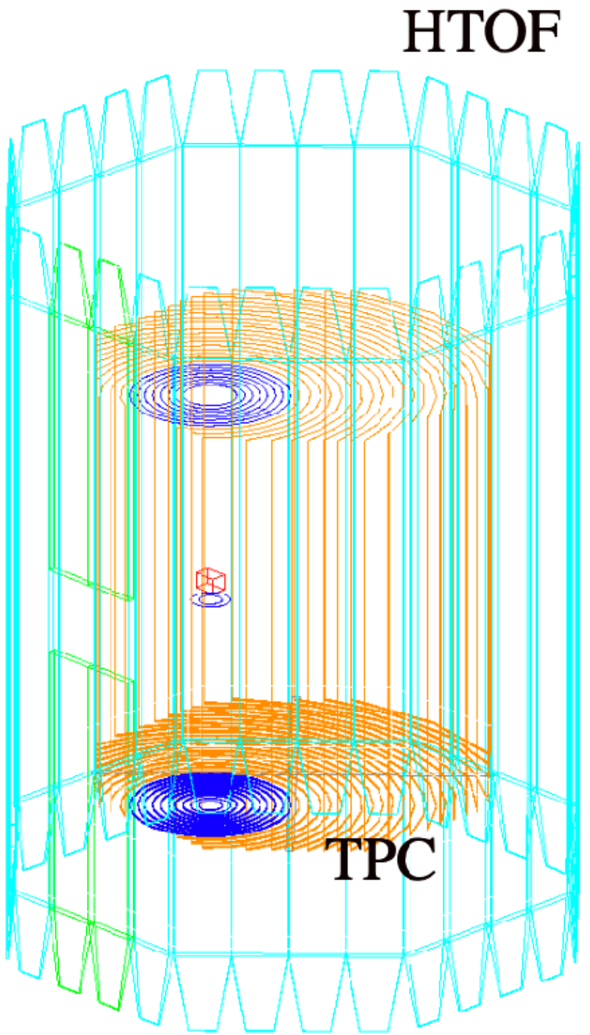
Magnet temperature





Online event display

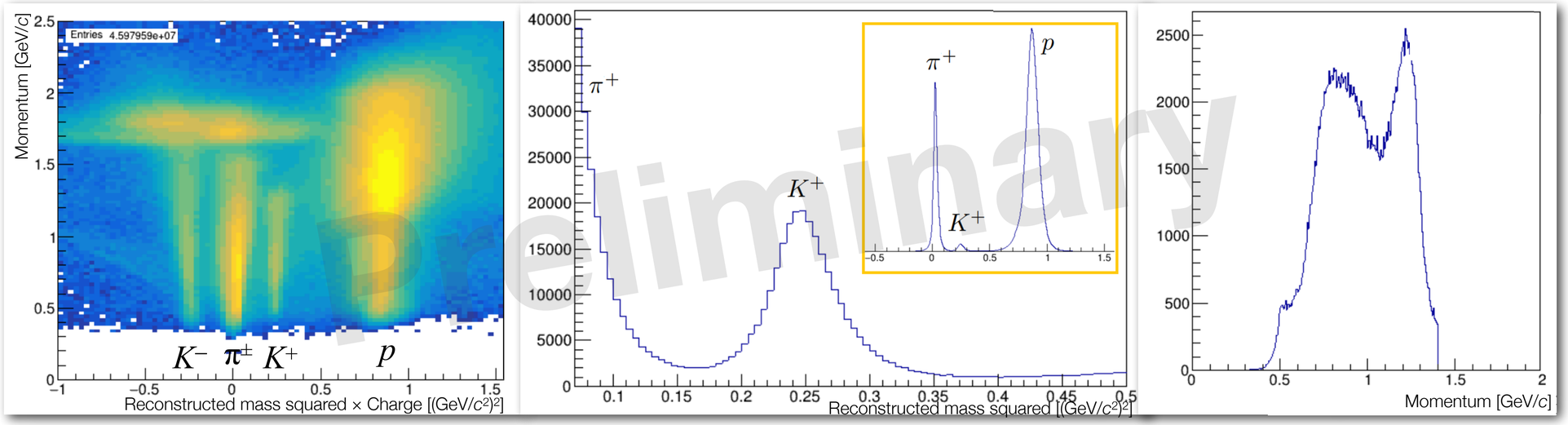




V tracks clearly seen

Analysis of (K^-, K^+) reaction

Scattered particles



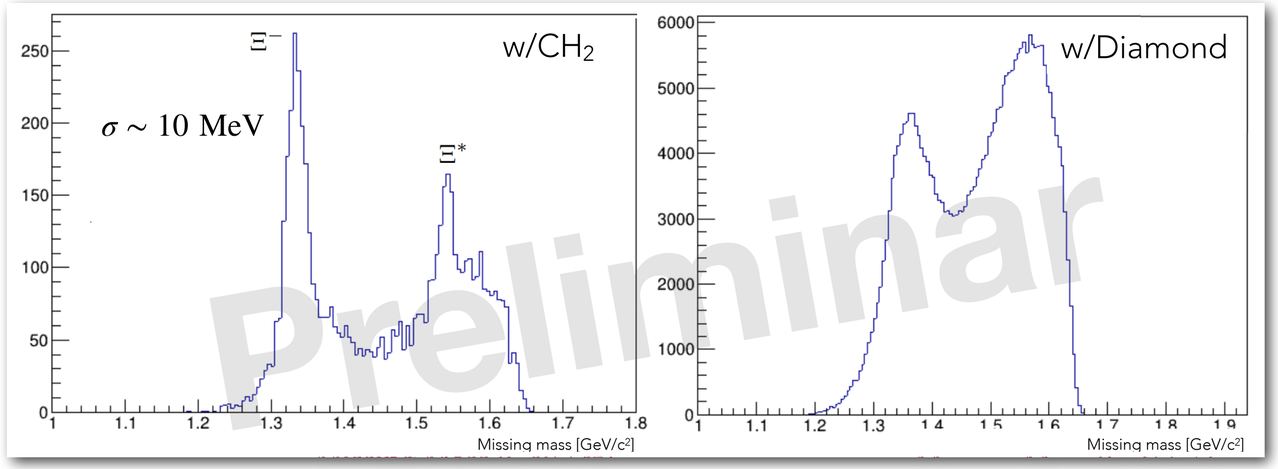
$^{12}\mathrm{C}(K^-, K^+)$

3×10^5 events

(KEK E522 : 45934 events)

K^+ : 0.5-1.4 GeV/c

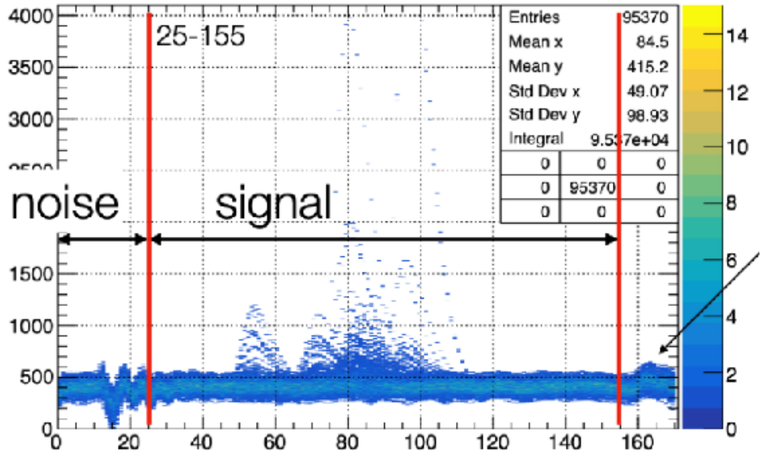
Missing mass



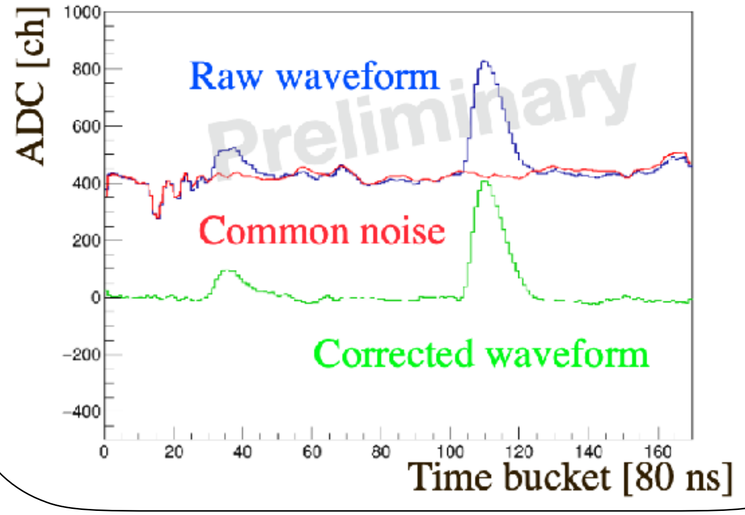
→ Hyperon Spectrometer (HypTPC) in progress

Calibration status of HypTPC

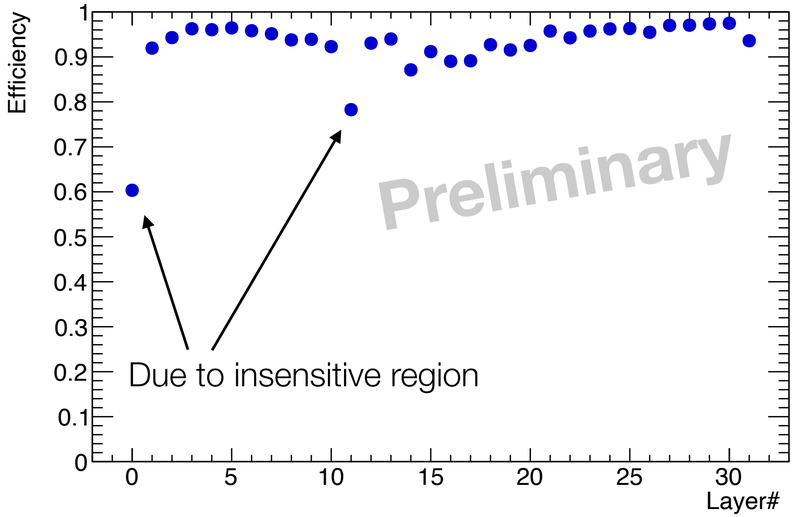
FADC Waveform



FADC Signal Baseline Correction



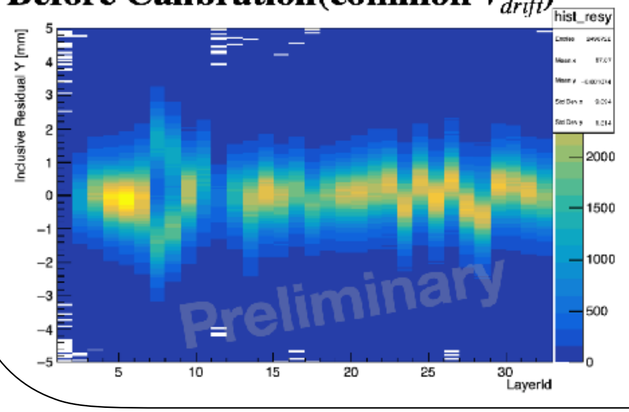
Detection efficiency for MIP



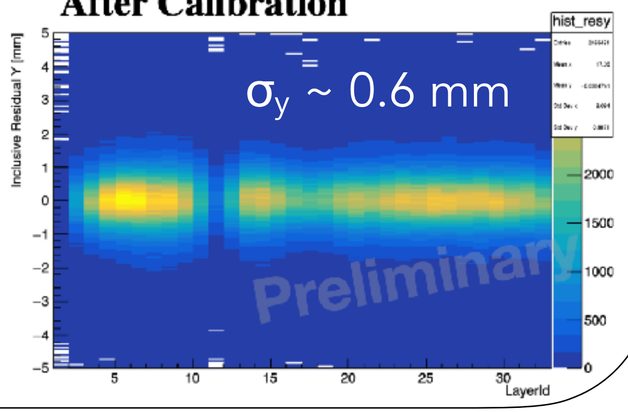
layer efficiency of
~94% on average.

Drift time calibration

Before Calibration(common V_{drift})



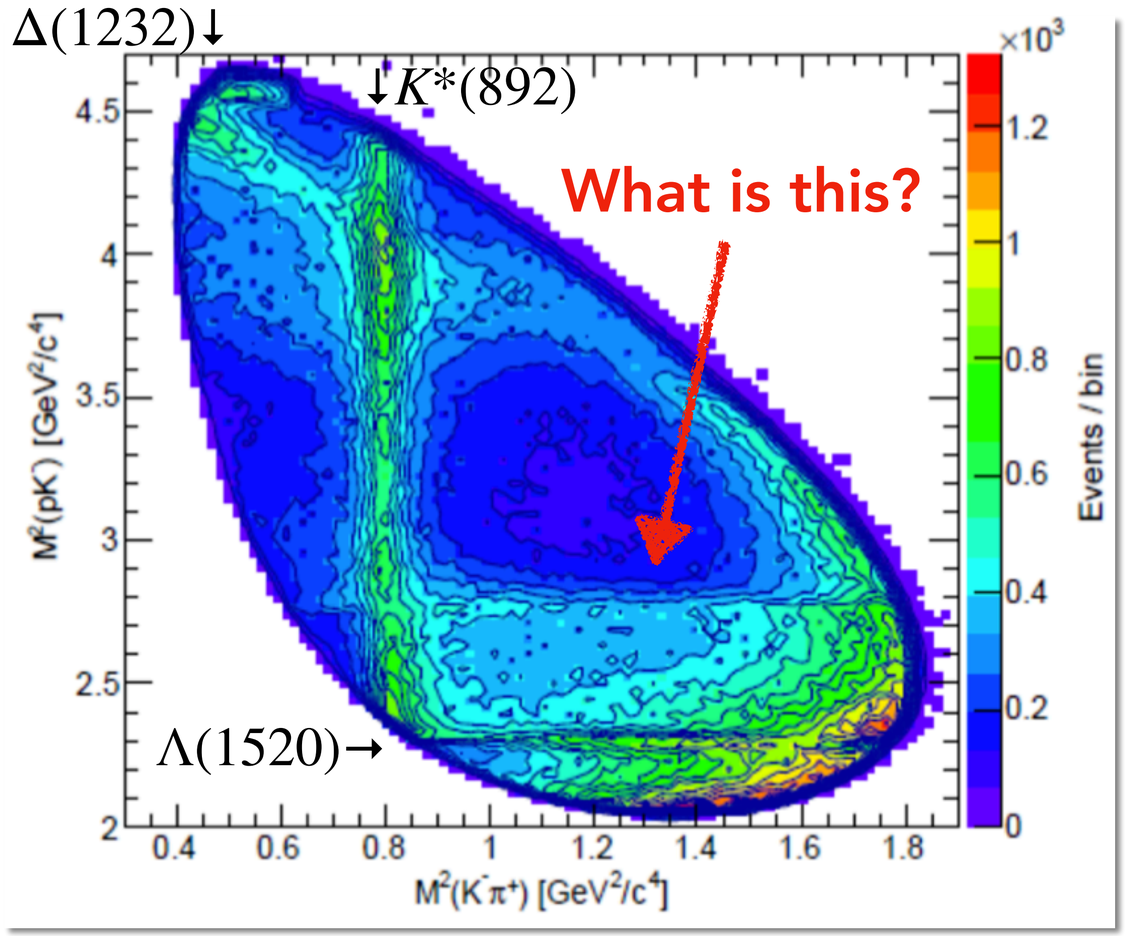
After Calibration

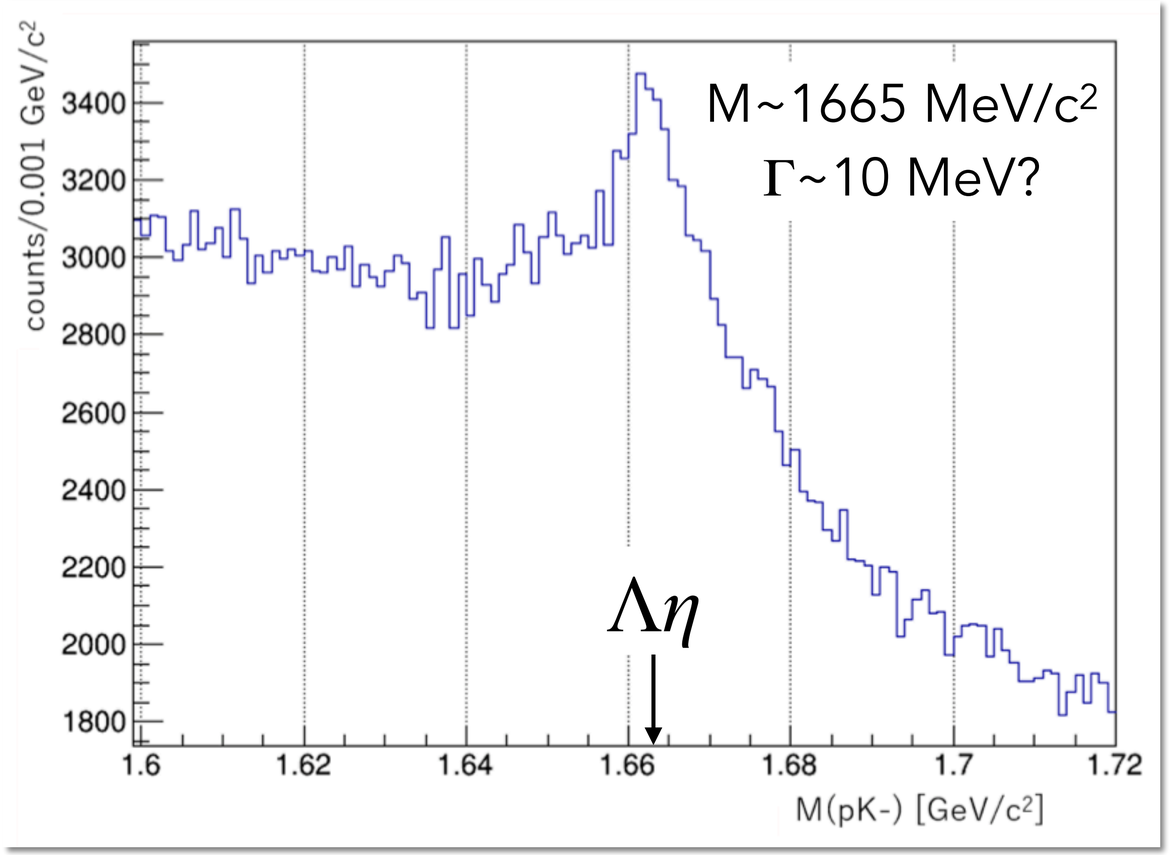


→ The momentum analysis part is being checked with simulations.

Narrow Λ* search experiment, J-PARC E72

Dalitz plot: $\Lambda_c^+ \to pK^-\pi^+$ Belle, PRL 117, 011801 (2016)





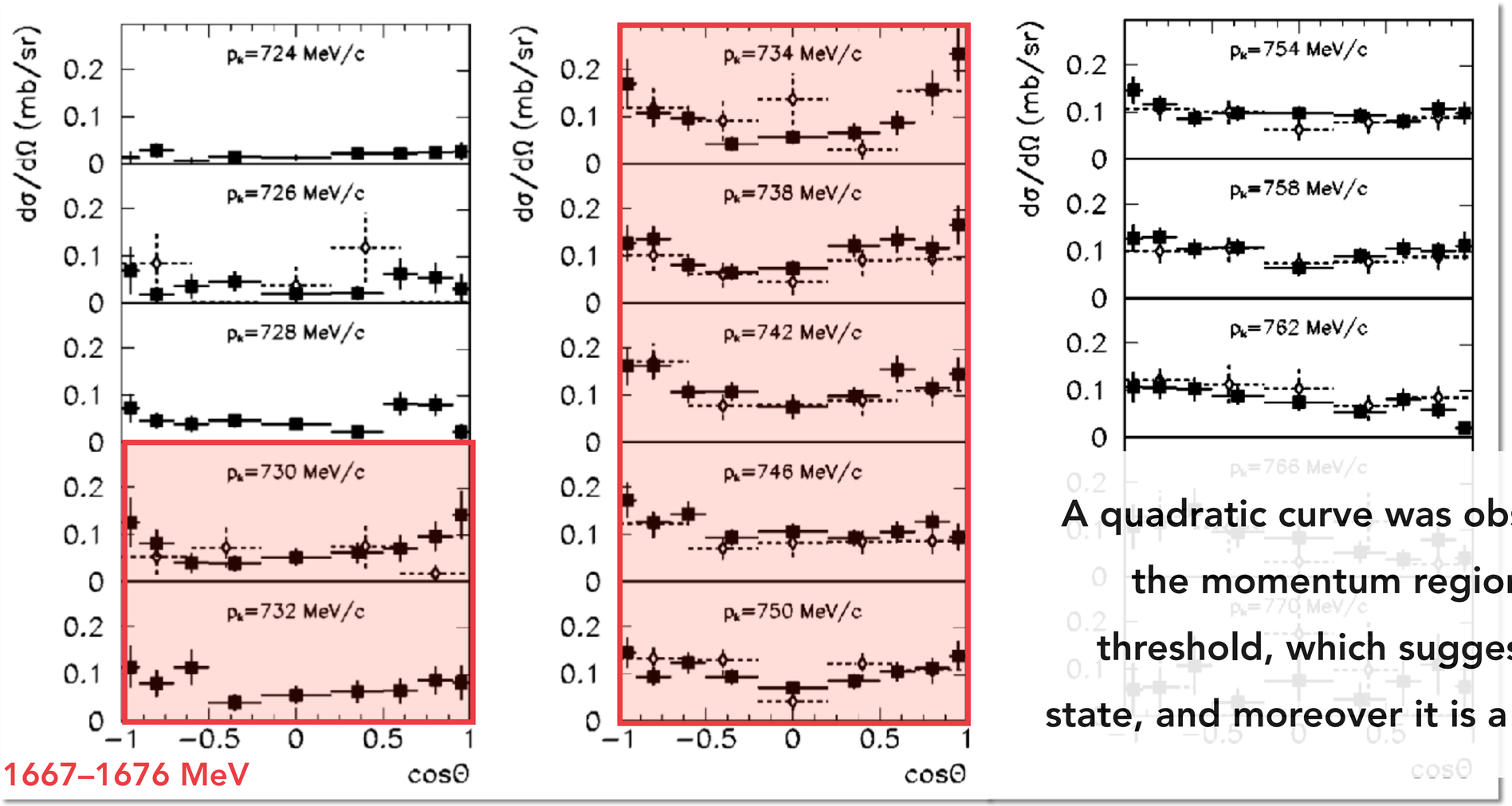
A narrow peak was observed at $M(pK^-)$ ~ 1665 MeV/c² just above the $\Lambda\eta$ threshold.

Differential cross sections for $K^- p \to \Lambda\eta$

Crystal Ball, PRC 64, 055205 (2001)

■ : $\eta \to \gamma\gamma$
□ : $\eta \to 3\pi^0$

Flat **Quadratic** **Flat**



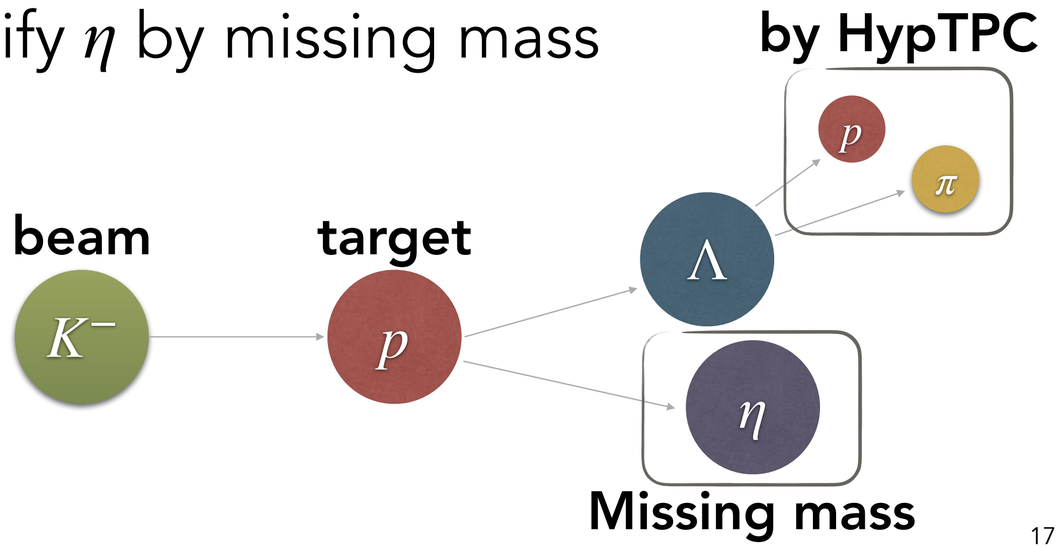
√s = 1667–1676 MeV

A quadratic curve was observed only in the momentum region near the threshold, which suggests a narrow state, and moreover it is a spin 3/2 state.

J-PARC E72 experiment

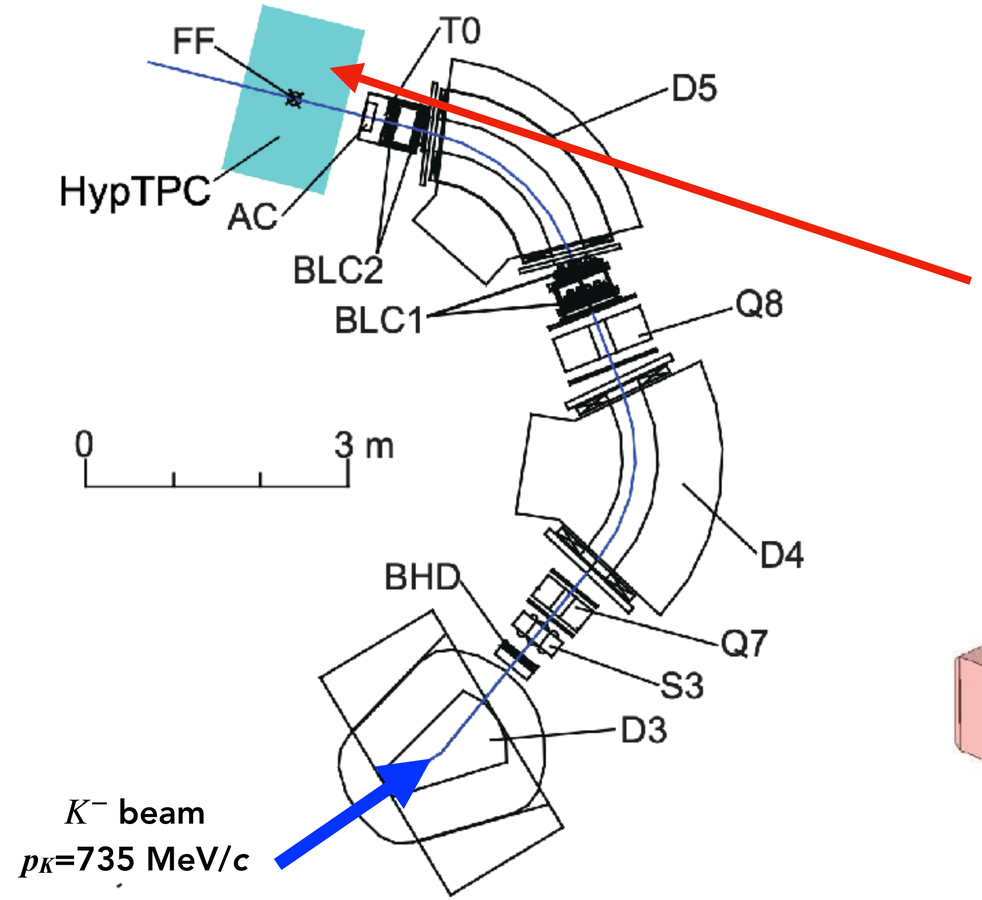
E72 aims to establish spin 3/2 $\Lambda(1665)$ and to determine its parity

- The $K^- p \to \Lambda\eta$ experiment using a large acceptance detector, HypTPC with p_{K^-} = 735 MeV/c (±2% FWHM) @K1.8BR
- K^- momentum resolution $\delta p/p$ ~ 1.5 MeV/c
  can identify narrow resonance down to Γ ~ 1 MeV
- Detect $\Lambda \to p\pi^-$ by invariant mass and identify η by missing mass
- Angular distribution → existence, spin
- Λ polarization → parity



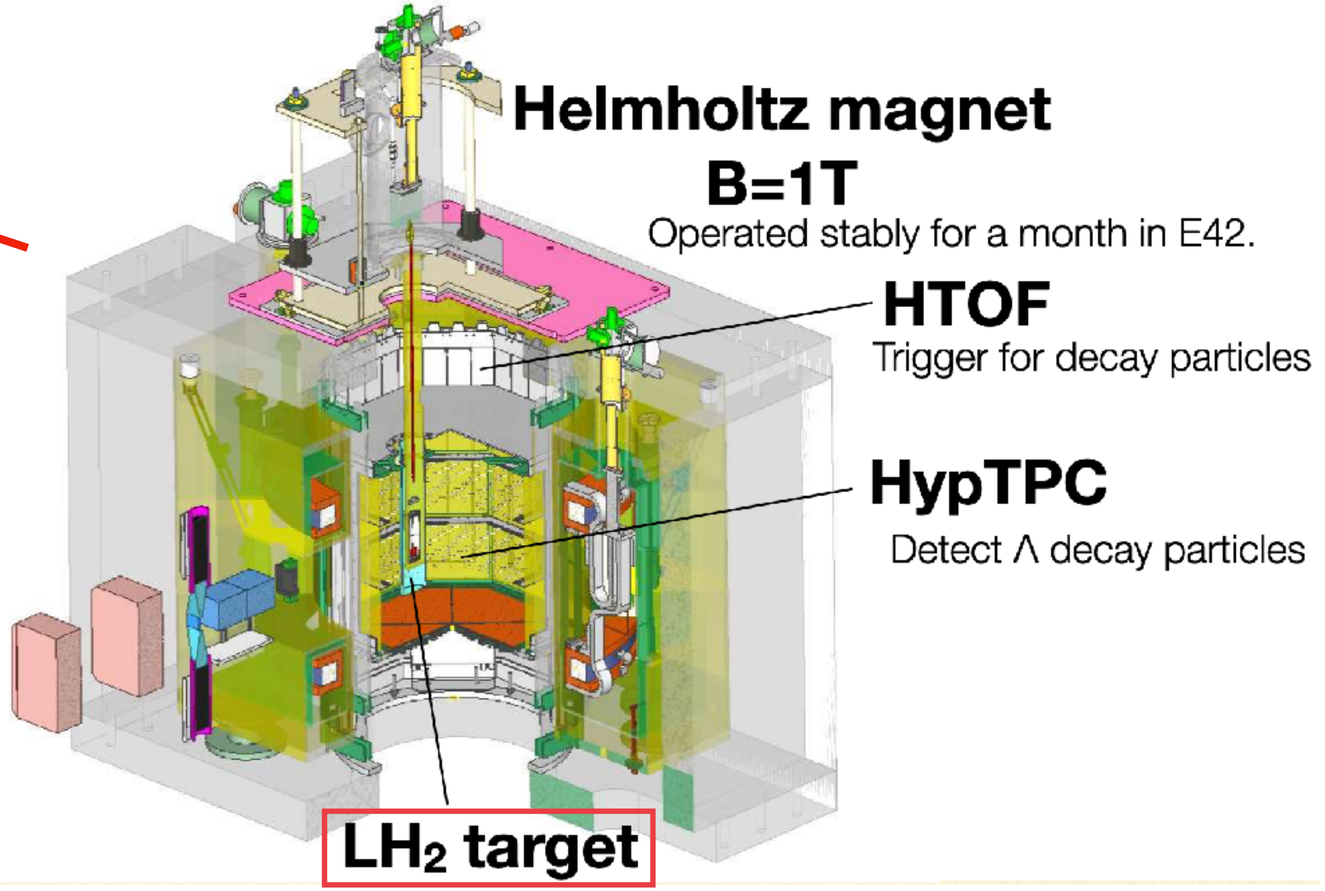
Experimental setup

Hyperon Spectrometer



@K1.8BR beam line

Main parts are common to E42



need to be newly developed

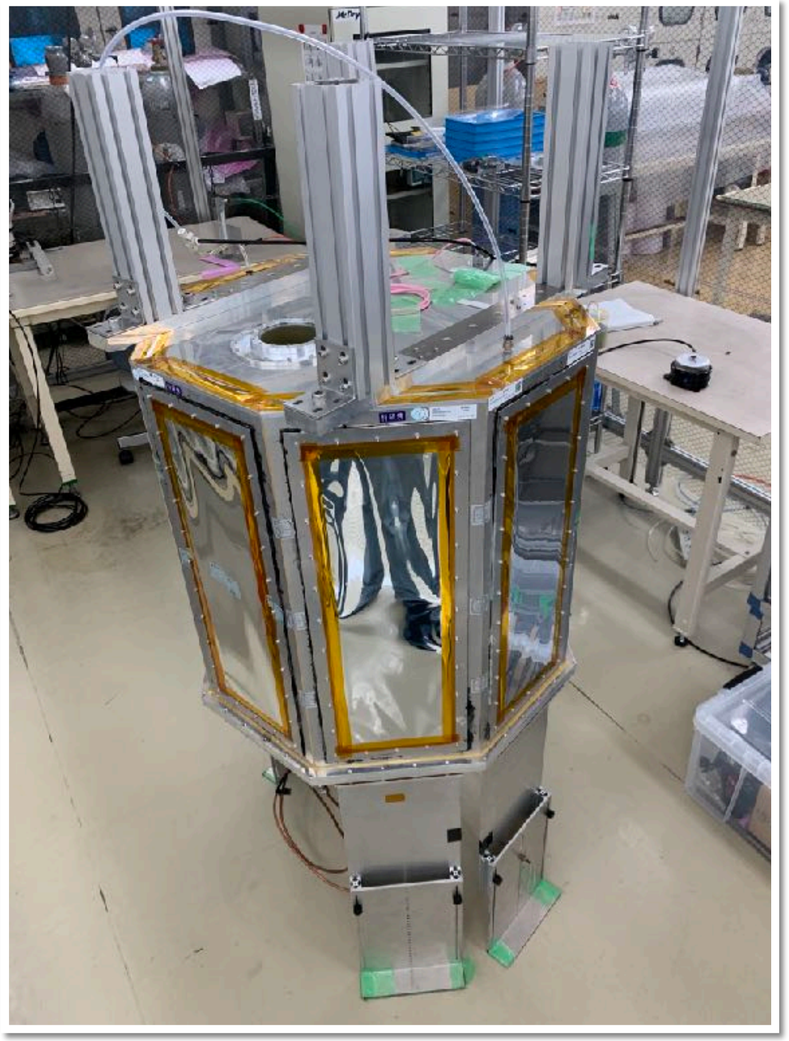
Target holder of HypTPC

We are testing gas tightness using a target holder for LH_2.

We also plan to increase the size of the target and will soon start production.

Target holder for LH_2

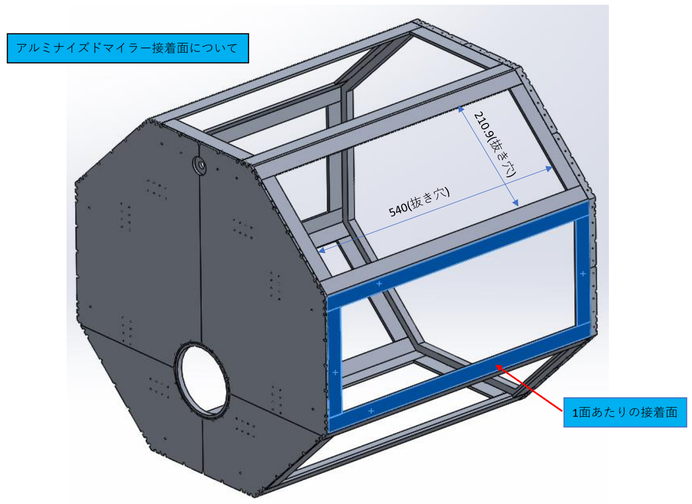
After installation

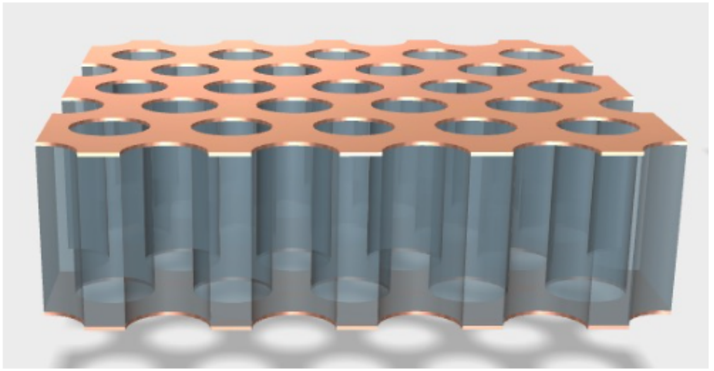


Future upgrades

- Thiner aluminum frame of HypTPC
- Glass GEM with better discharge resistance
- Noise reduction of gating grid pulser

Not everything will be finished by E72, though.





Summary

- **Hyperon Spectrometer** : SC magnet + HypTPC + HTOF
  - Measure decay particles and identify final state
- J-PARC E42 : **H dibaryon search**
  - Stably operated SC magnet and HypTPC
  - HypTPC calibration is in progress
- J-PARC E72 : **Narrow Λ* search**
  - Development and preparation is ongoing
  - will be performed in 2024~