



14th International Workshop on the Physics of Excited Nucleons
York, UK, Jun 17-21, 2024

Baryon Spectroscopy in 3-Body Hadronic Reactions at J-PARC



Shin Hyung Kim
(Kyungpook National University)
for the J-PARC E45 Collaboration



Introduction

Missing Resonance Problem

- ▶ the excited spectrum of hydrogen → a deeper understanding of QM

PDG 2022

N	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	****
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	***
$N(1895)$	$1/2^-$	****
$N(1900)$	$3/2^+$	****
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	***
$N(2100)$	$1/2^+$	***
$N(2120)$	$3/2^-$	***
$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	****
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	***
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*

**** Established

 * **

- ▶ Many resonances have not been established experimentally.

- ▶ Most of the N^* s so far were measured from

$$\pi N \rightarrow \pi N, \gamma N \rightarrow \pi N, \gamma N \rightarrow \pi\pi N$$

- ▶ $\pi N \rightarrow \pi\pi N$ data are necessary to resolve remaining resonances

Missing Resonance Problem

- ▶ the excited spectrum of **the nucleon** → a deeper understanding of **QCD**

PDG 2022

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- ▶ Many resonances have not been established experimentally.

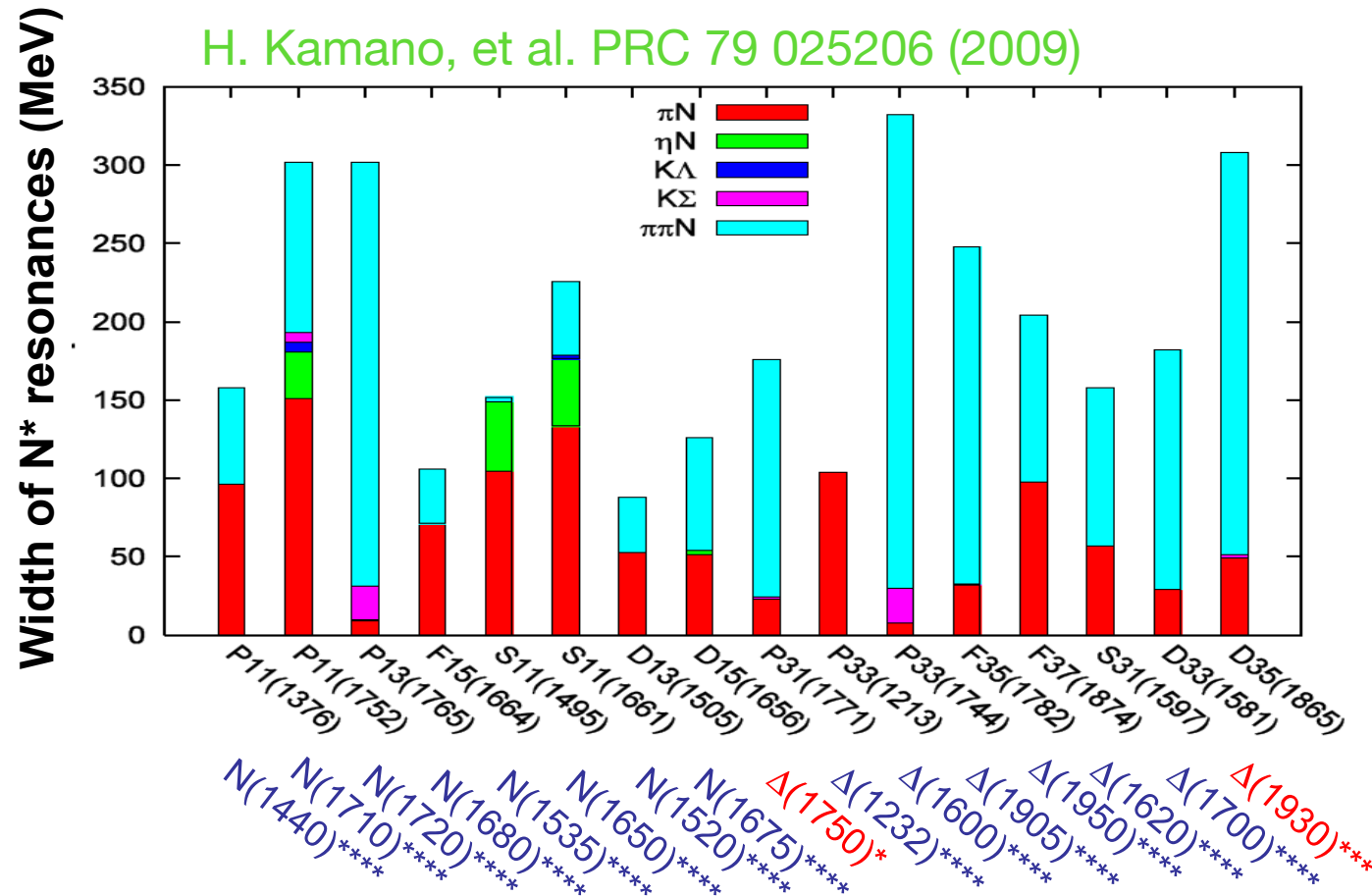
- ▶ Most of the N^* s so far were measured from

$$\pi N \rightarrow \pi N, \gamma N \rightarrow \pi N, \gamma N \rightarrow \pi\pi N$$

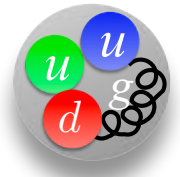
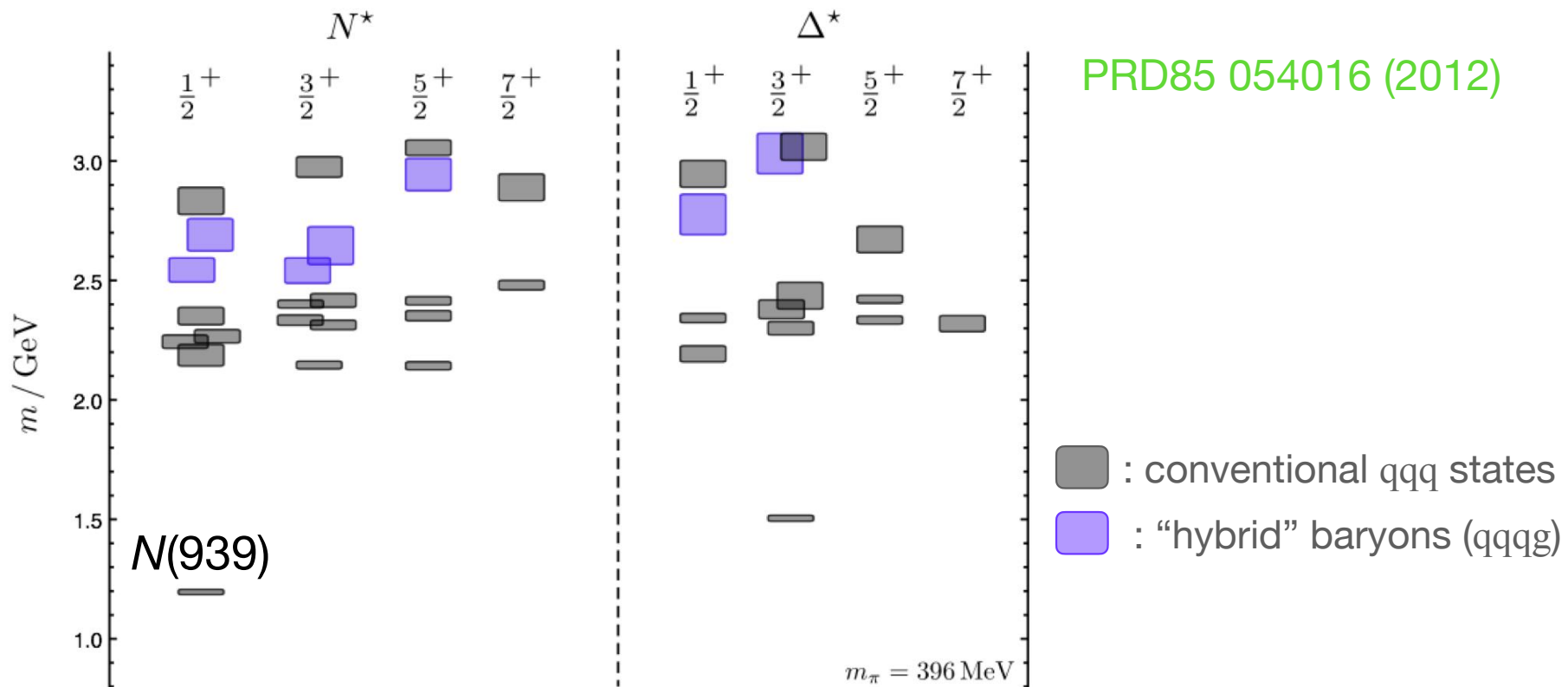
- ▶ $\pi N \rightarrow \pi\pi N$ data are necessary to resolve remaining resonances

Importance of $\pi\pi N$ Decay

- According to the dynamical coupled-channel calculation, there are many N^* and Δ^* resonances which couple to $\pi\pi N$ ($\pi\Delta$, ρN , σN) dominantly.



Lattice QCD Calculation

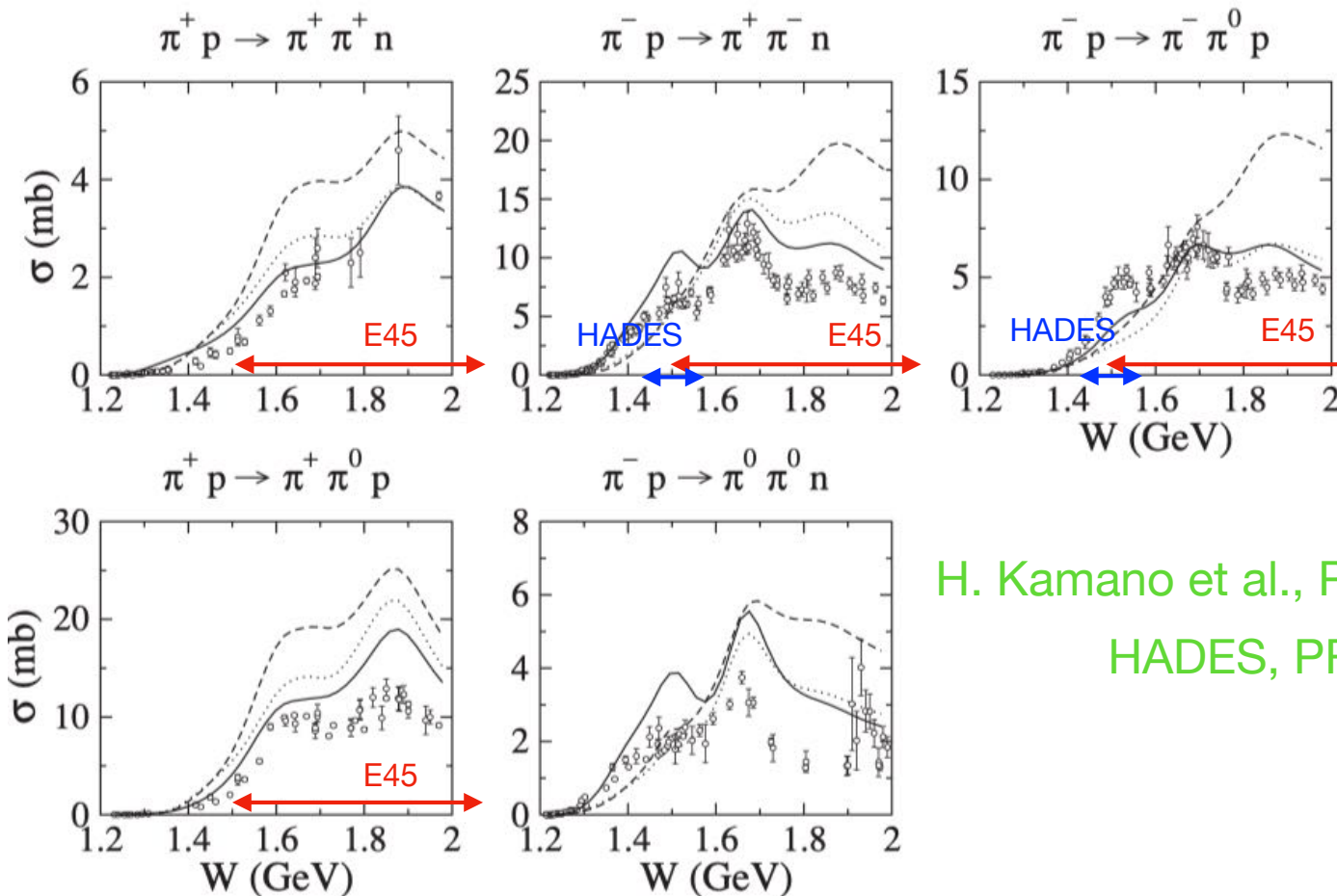


- ▶ Lattice QCD calculation predicts that **hybrid baryons** should exist.
- ▶ Preliminary indications from photoproduction data at CLAS suggest an extra resonance, in addition to the known quark-model resonances in $\gamma p \rightarrow \pi^+ \pi^- p$ reaction. → Complementary hadronic data are necessary.

PLB805 135457 (2020)

J-PARC E45: N^* Baryon Spectroscopy

- ▶ N^* spectroscopy with the $\pi p \rightarrow \pi\pi N$ reactions in the wide energy range of 1.5 - 2.15 GeV ($p=0.73 - 2.0$ GeV/c) using high intensity beam at J-PARC.
- ▶ Updates on the world database ($\pi p \rightarrow \pi\pi N$)
 - ▶ 240k events measured in 1970's \rightarrow $\times 100$ higher statistics



H. Kamano et al., PRC 79, 025206 (2009)
 HADES, PRC 102, 024001 (2020)

J-PARC E45 Experiment

J-PARC E45 Collaboration [*co-spokespersons](#)

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[P. Cole](#)

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(KRISS)

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K. Shirotori, S. Y. Ryu, H. Kamano

(RCNP)

V. Shklyar

(Univ. Giessen)

A. Svarc

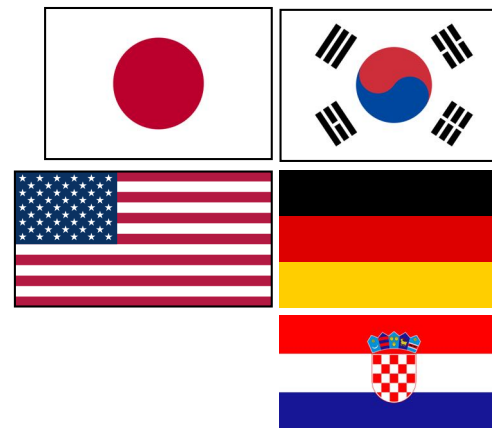
(Ruder Boskovic Institute)

S. Ceci

(RBI-Zagreb)

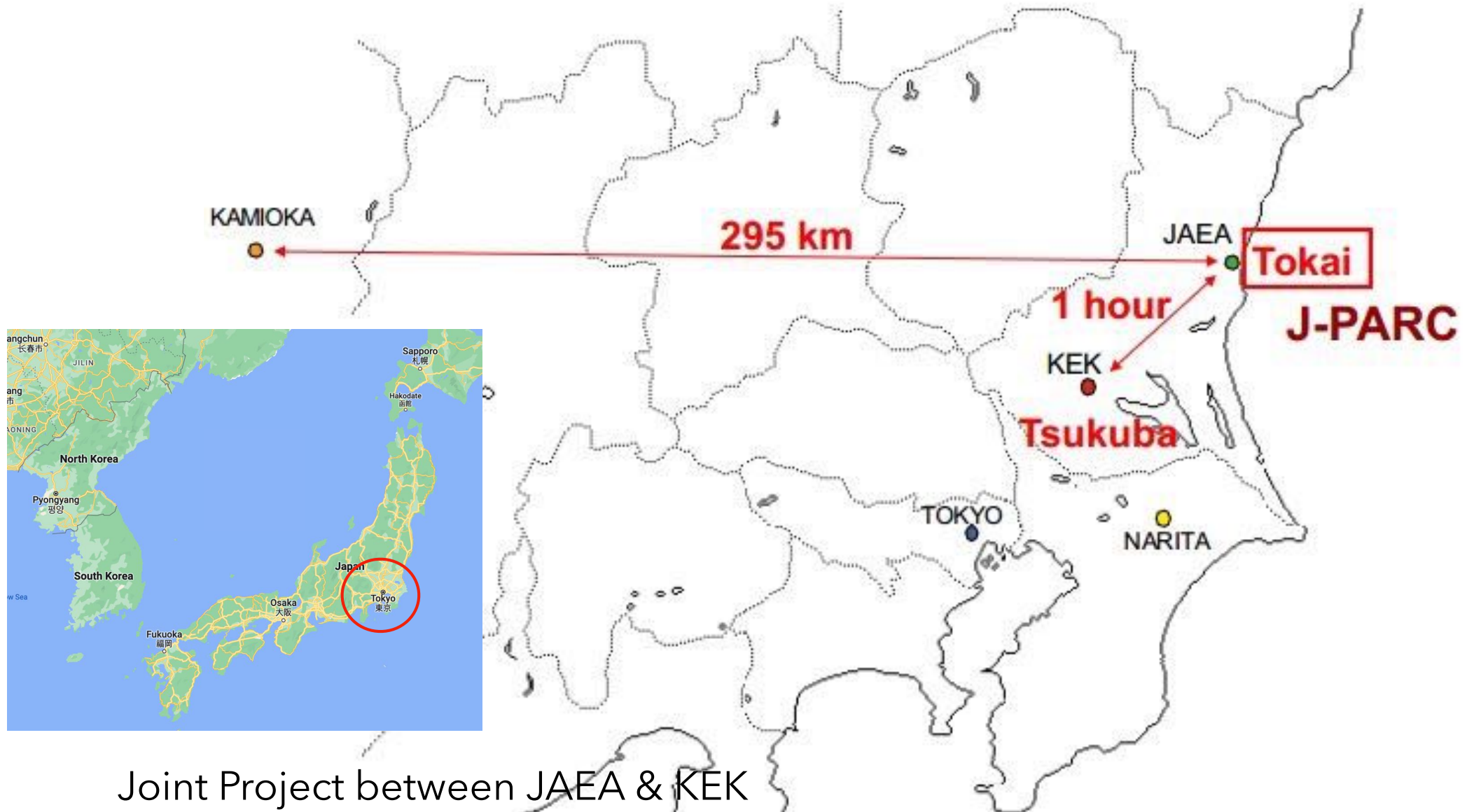
M. Hadzimehmedovic, H. Osmanovic

(Univ. Tulza)



J-PARC (Japan Proton Accelerator Research Complex)

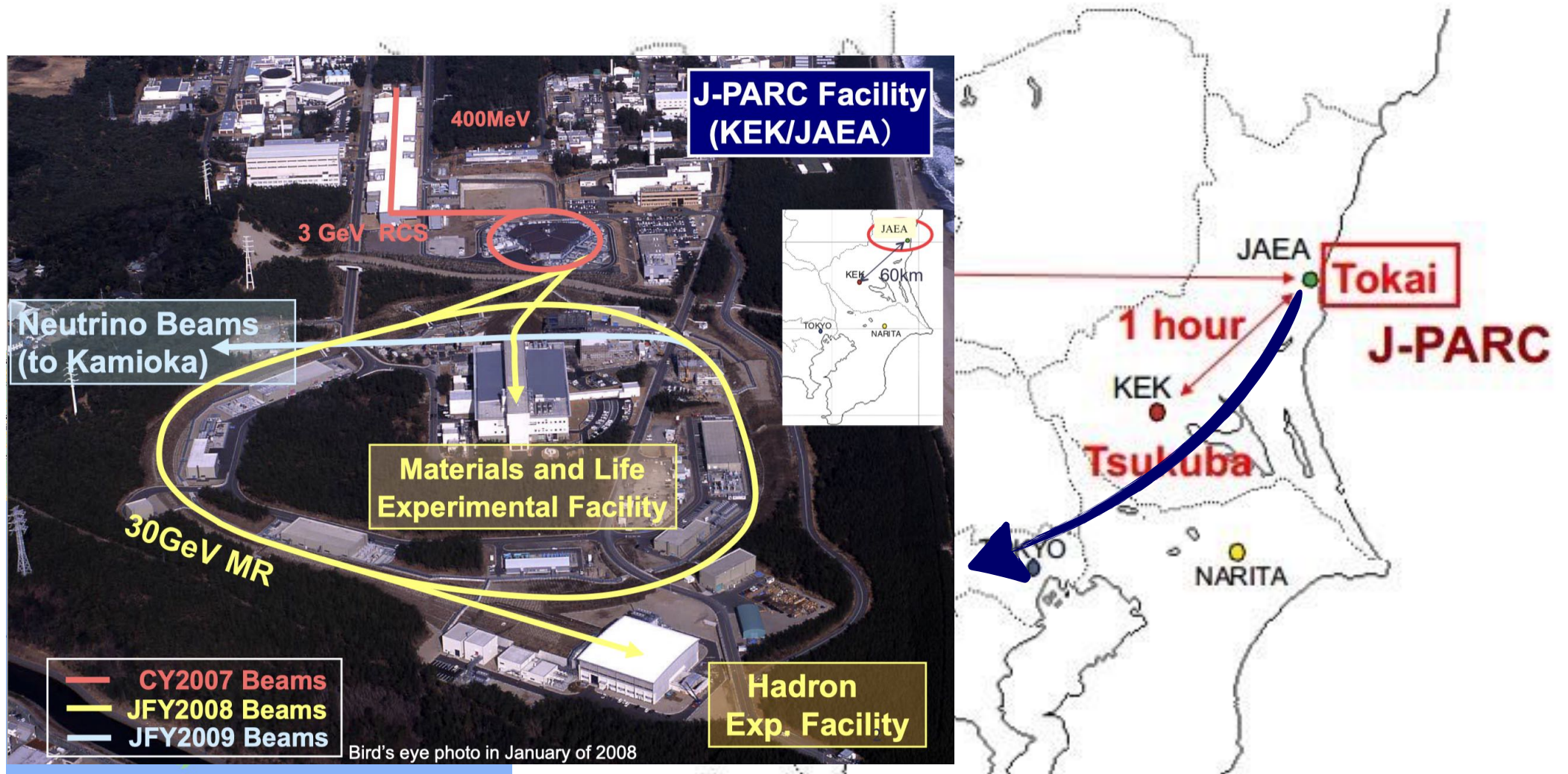
- ▶ the world's top class **high-energy and high-intensity** proton beam



Joint Project between JAEA & KEK

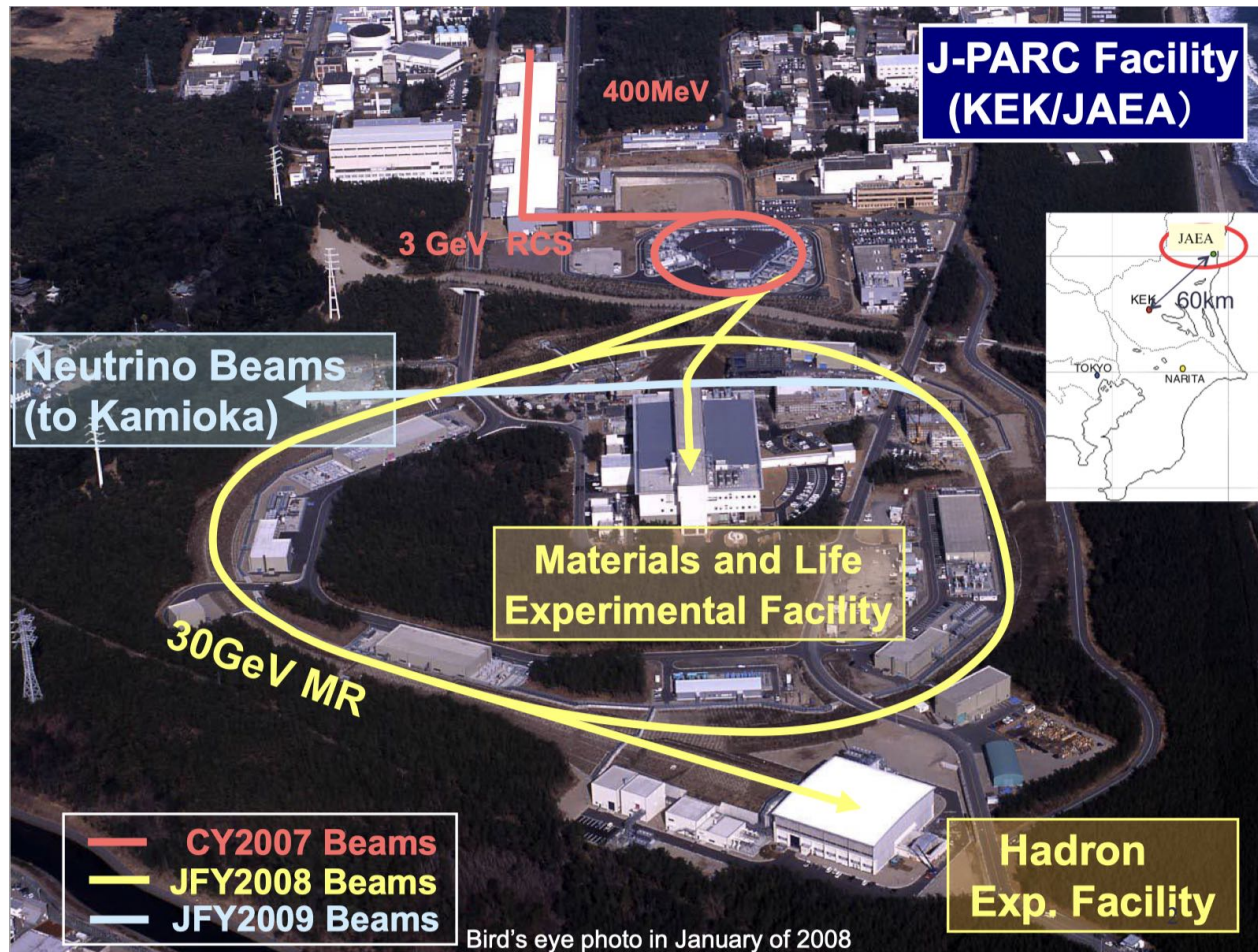
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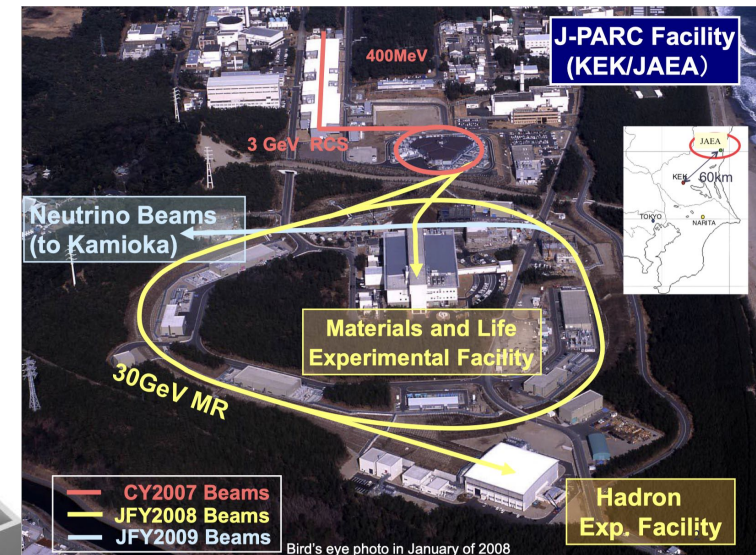
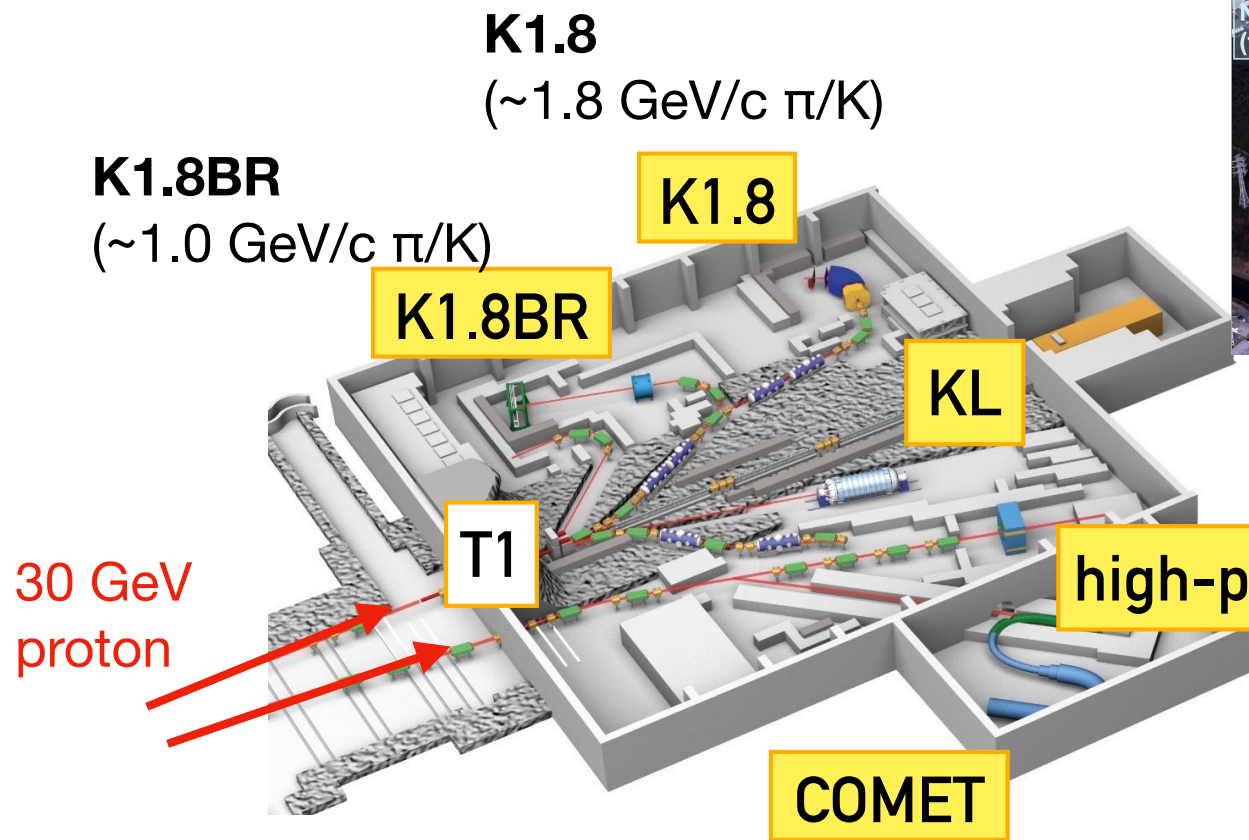


Joint Project between JAEA & KEK

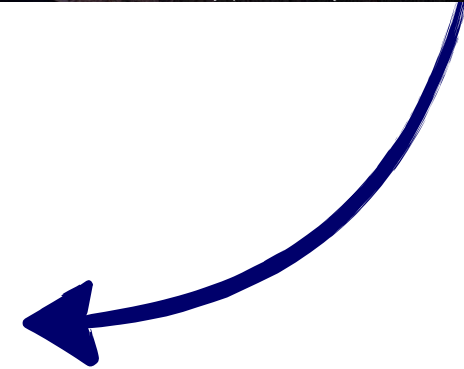
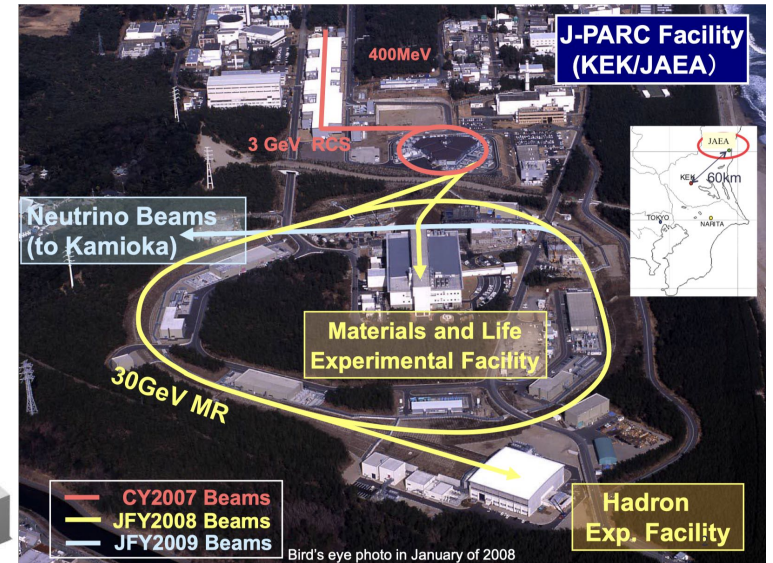
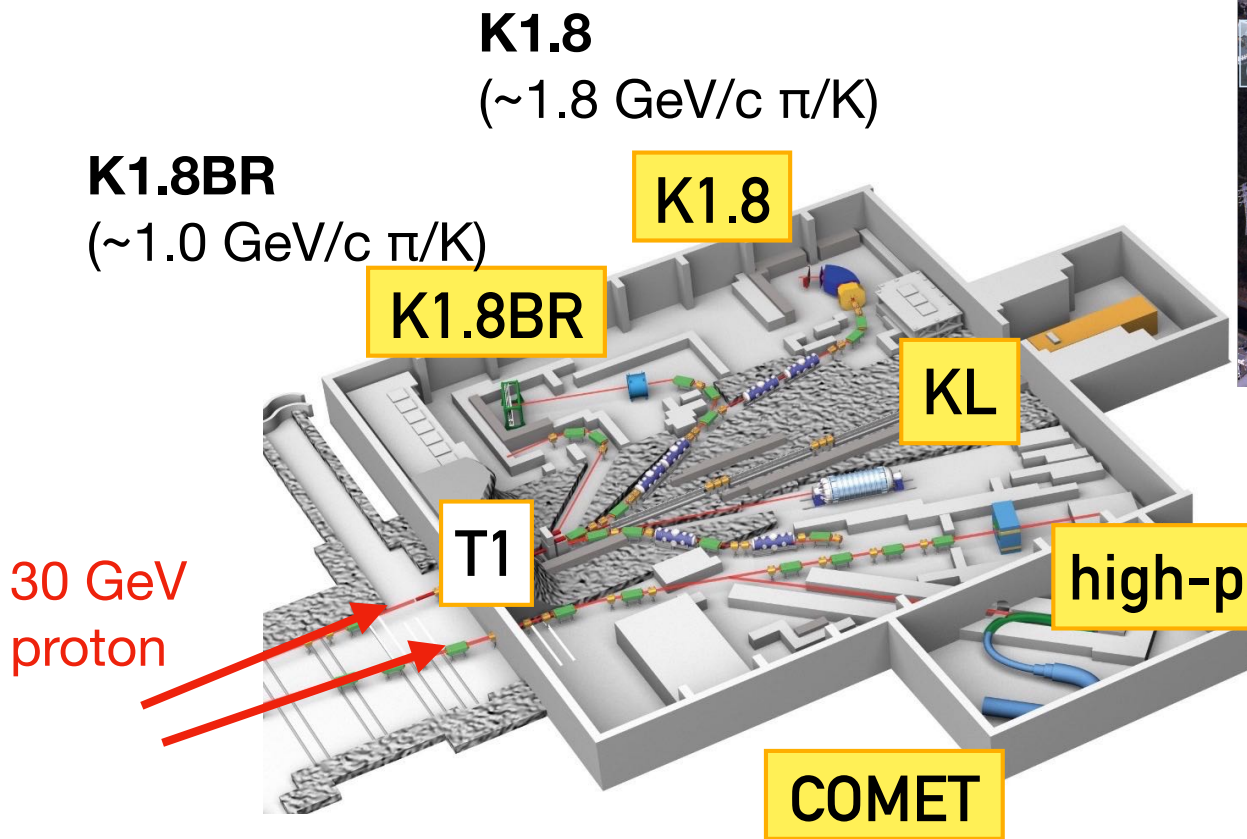
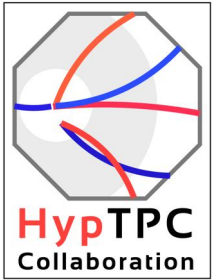
J-PARC Hadron Experimental Facility



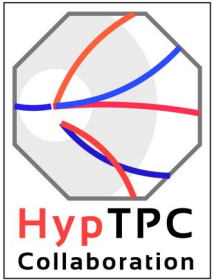
J-PARC Hadron Experimental Facility



HypTPC Experiments at J-PARC



HypTPC Experiments at J-PARC



E72
Narrow Λ^* search

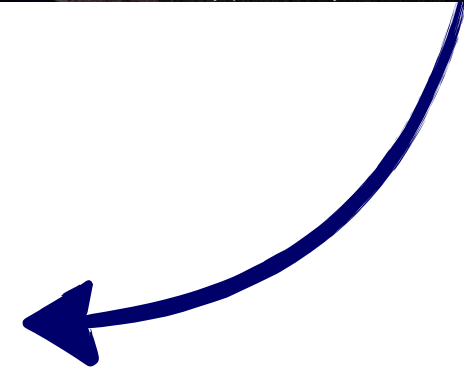
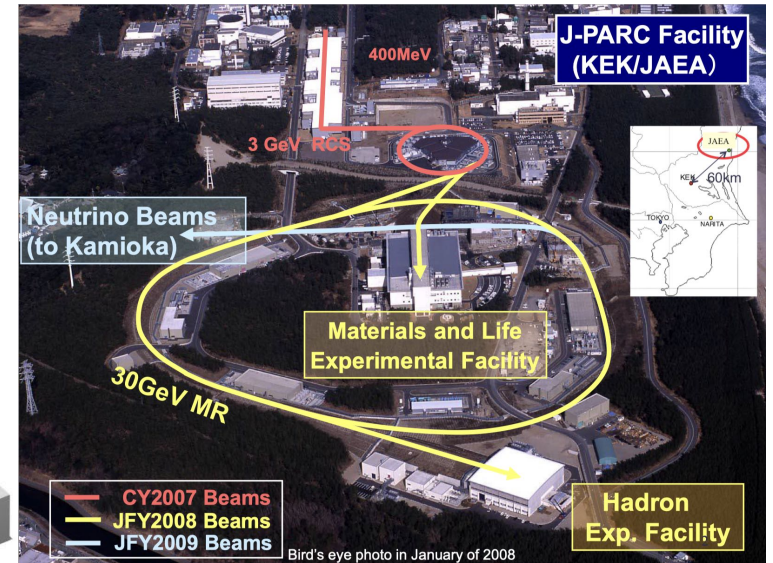
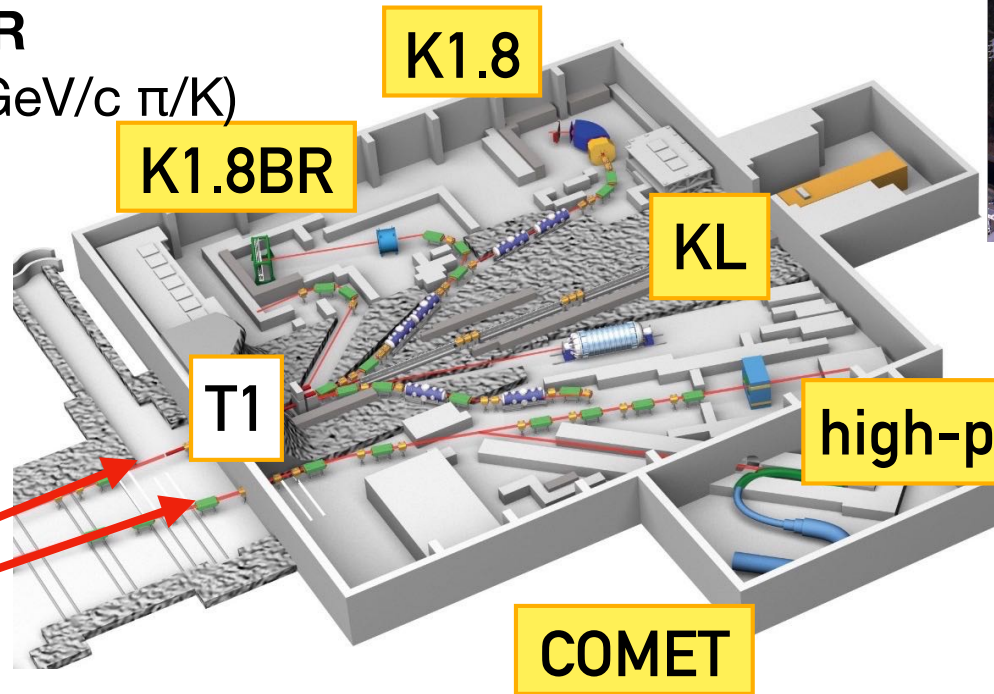
E42 H -dibaryon search

E90 ΣN cusp

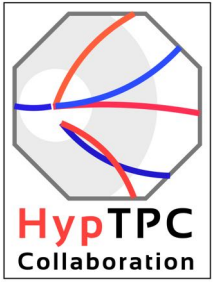
E45 N^* spectroscopy

K1.8
(~ 1.8 GeV/c π/K)

K1.8BR
(~ 1.0 GeV/c π/K)



HypTPC Experiments at J-PARC



E72
Narrow Λ^* search

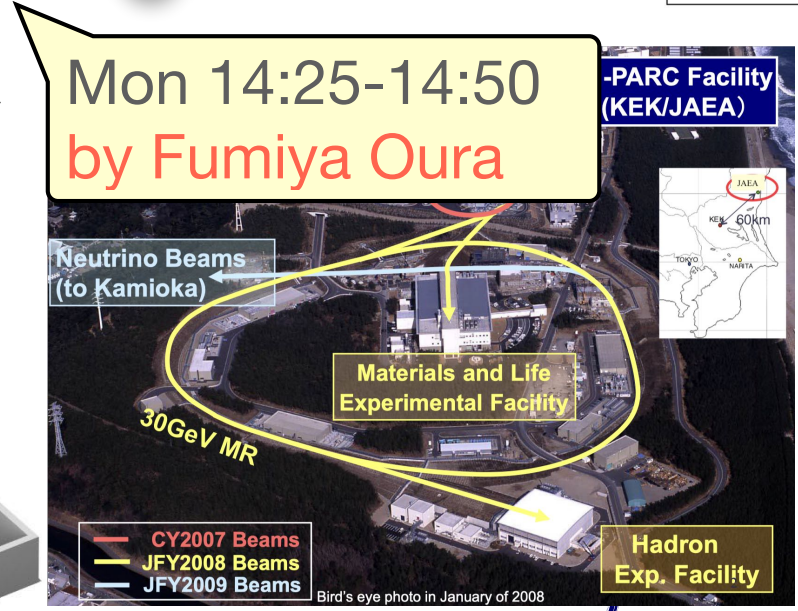
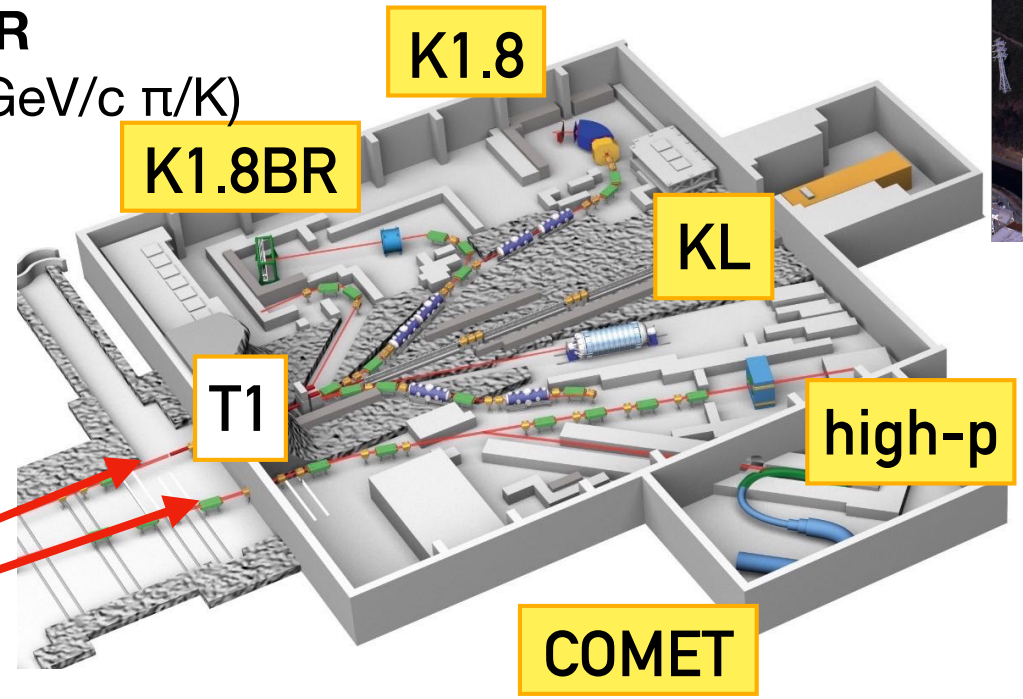
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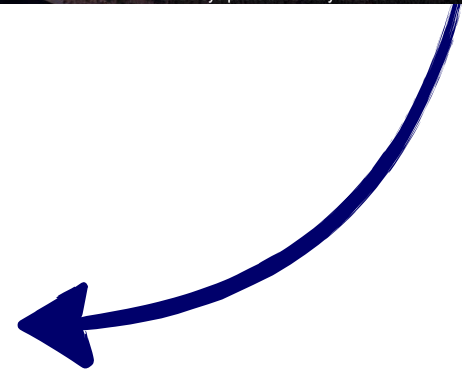
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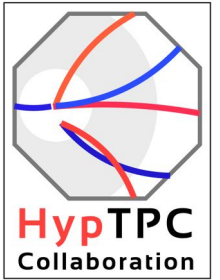
K1.8BR
(~ 1.0 GeV/c π/K)



30 GeV proton



HypTPC Experiments at J-PARC



E72
Narrow Λ^* search

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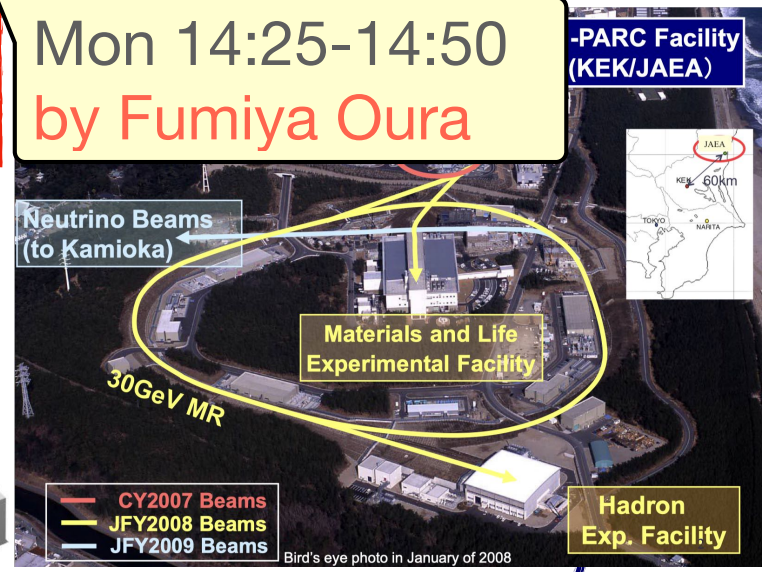
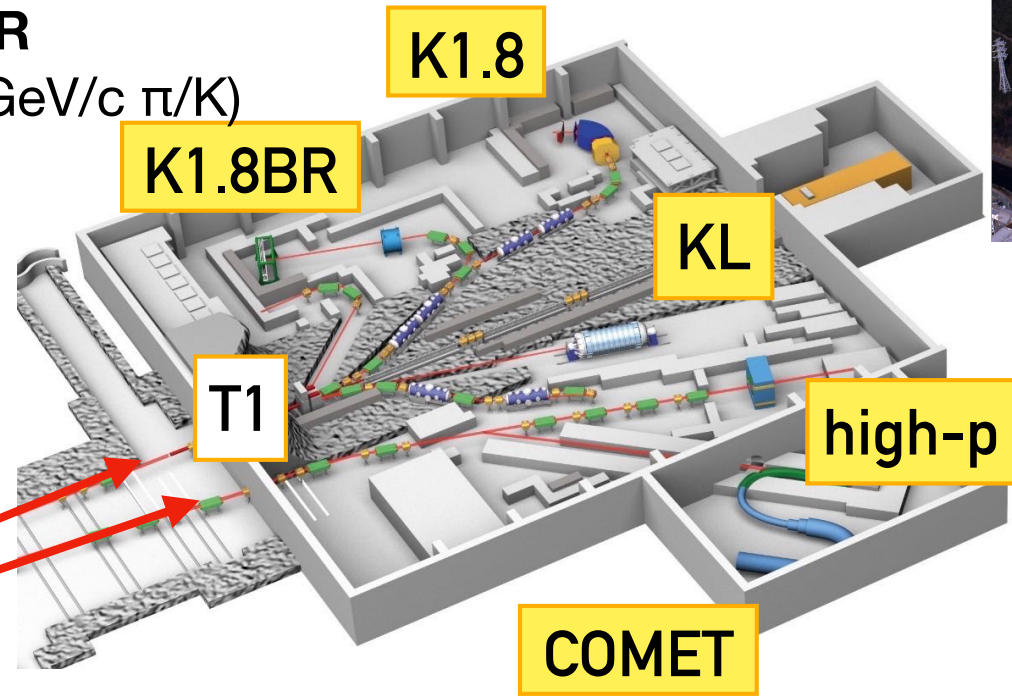
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E45 N^* spectroscopy

Mon 14:25-14:50
by Fumiya Oura

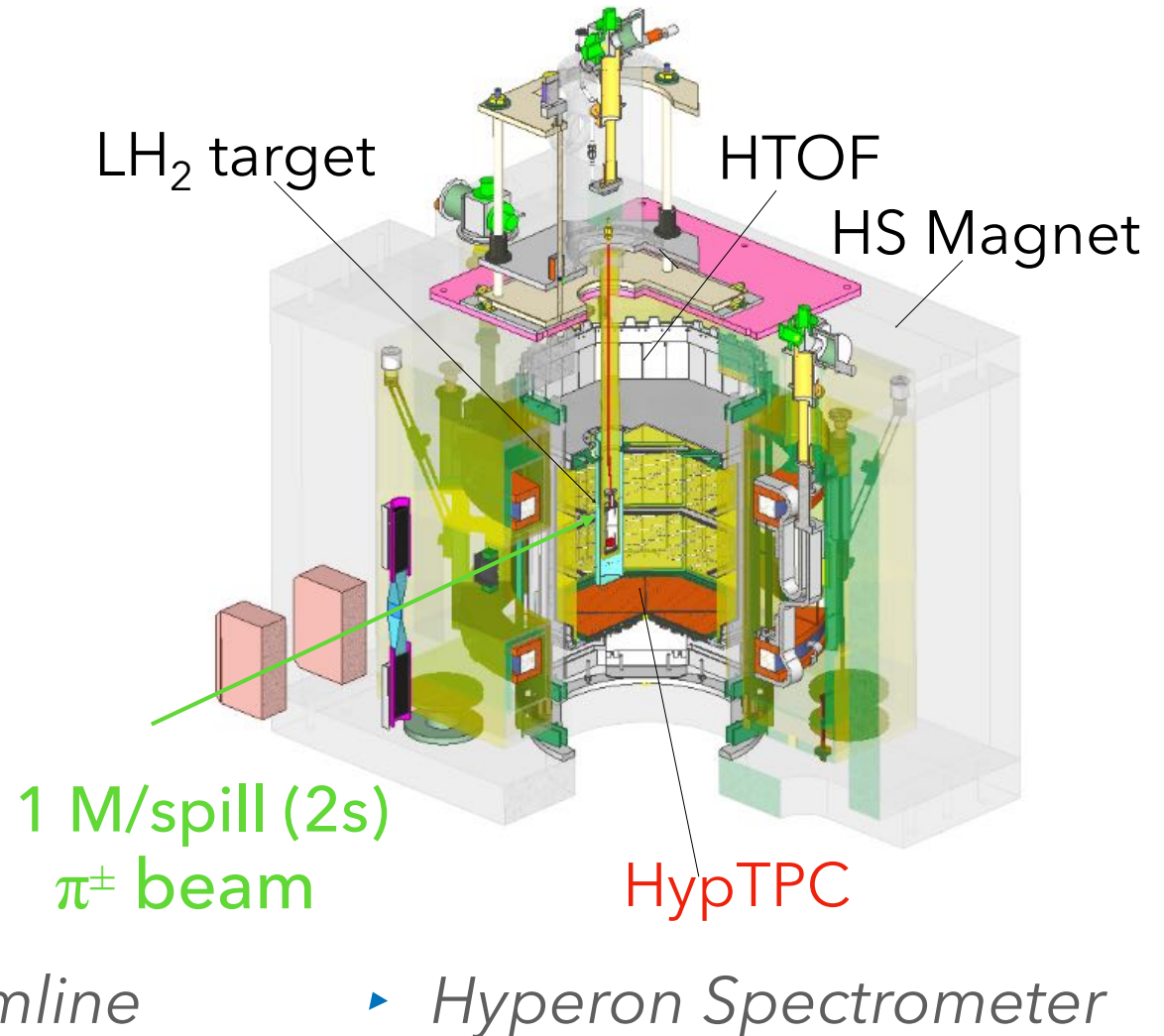
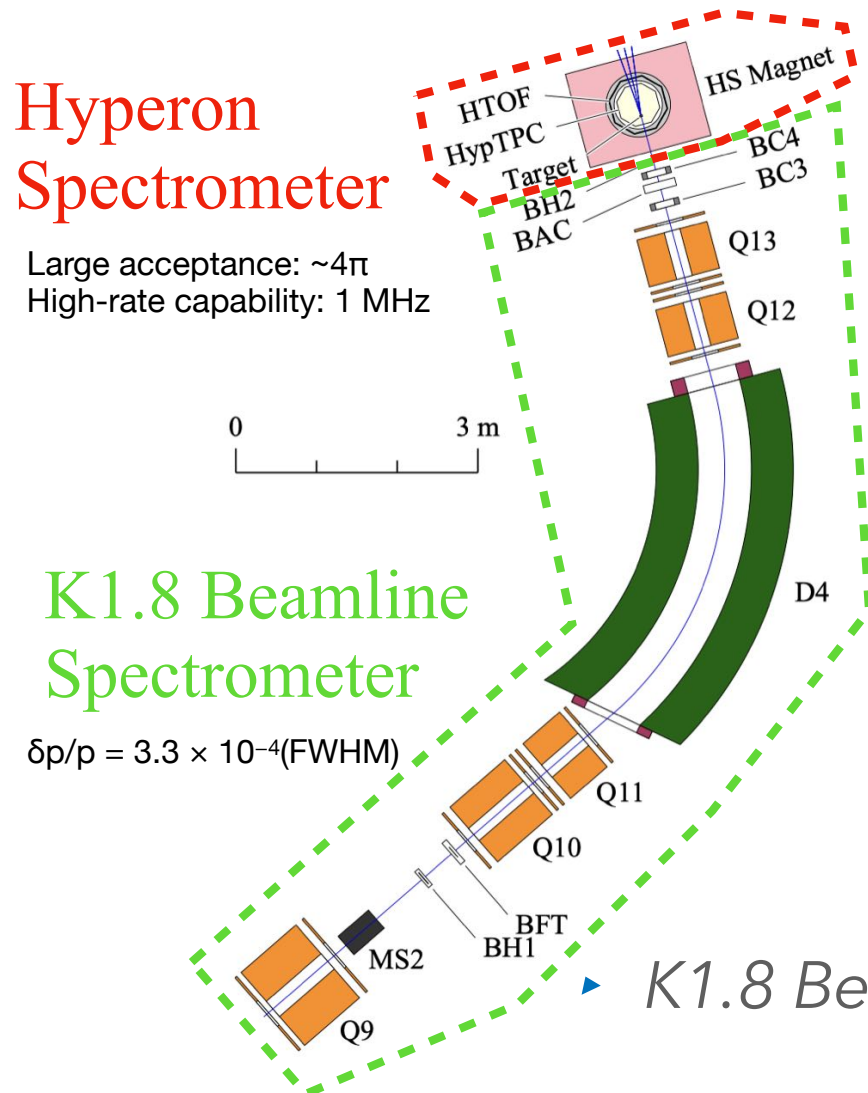
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(~ 1.8 GeV/c π/K)

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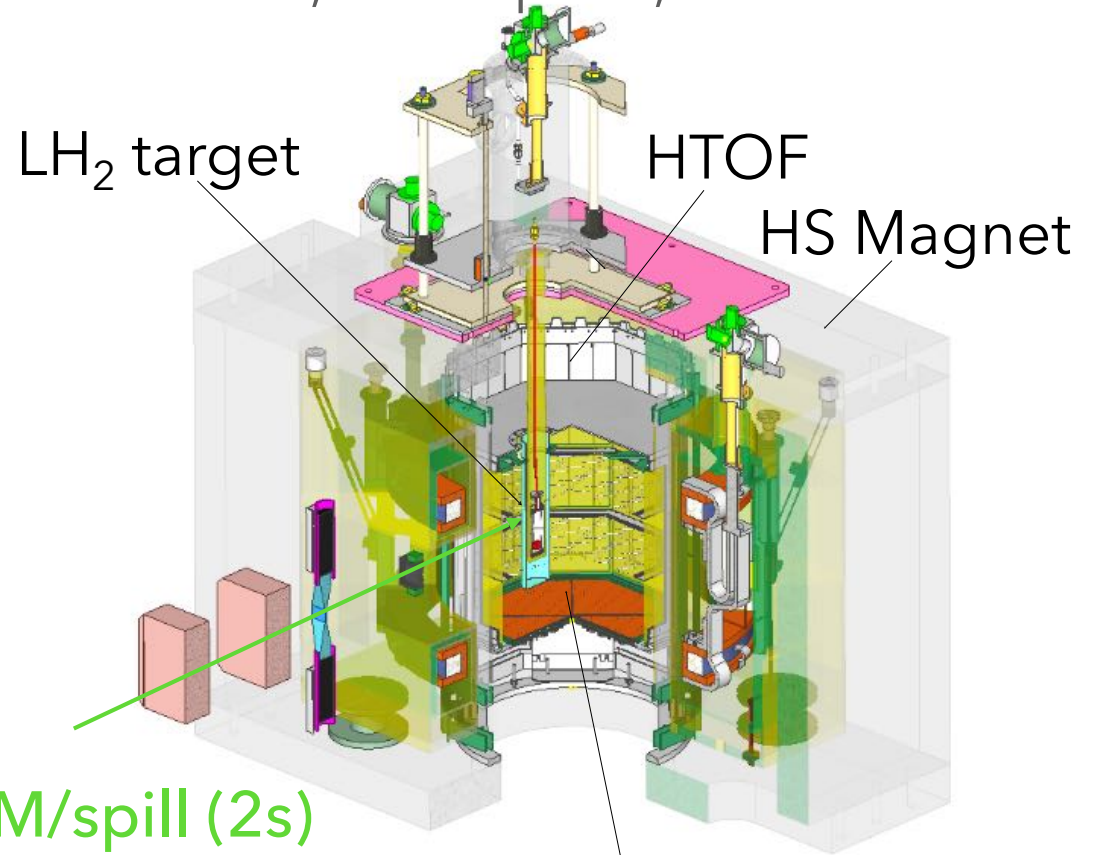
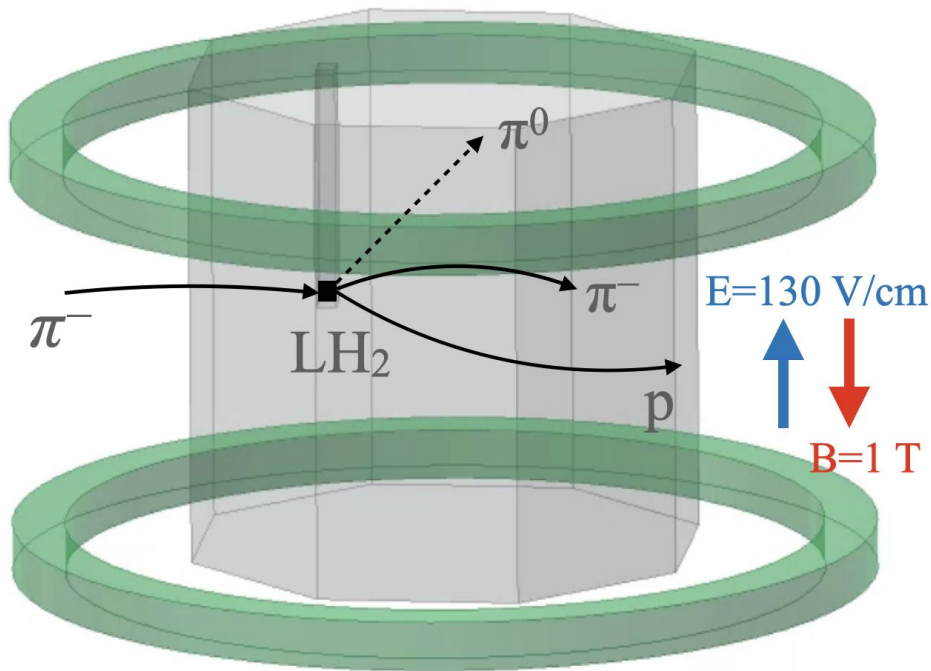
J-PARC E45 Experimental Setup

- ▶ N^* spectroscopy with the $\pi p \rightarrow \pi\pi N$ reactions in the wide energy range of 1.5 - 2.15 GeV ($p=0.73 - 2.0$ GeV/c) at J-PARC.



Hyperon Spectrometer

- ▶ Detect all charged particles' trajectories in 3D from the $\pi^\pm p$ reactions.
 → angular distributions, mass distributions, Dalitz plots, ...



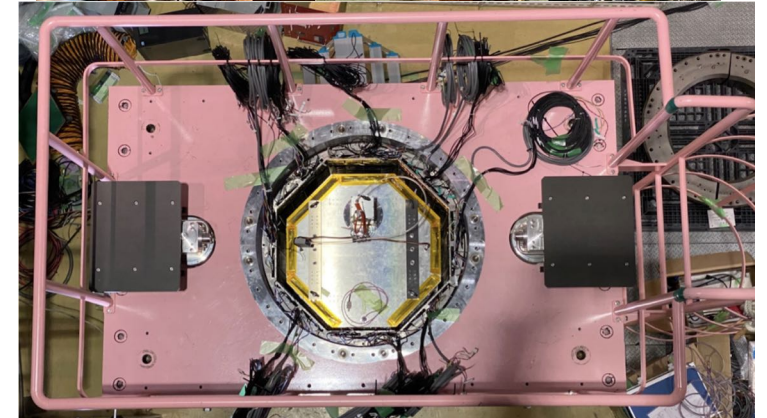
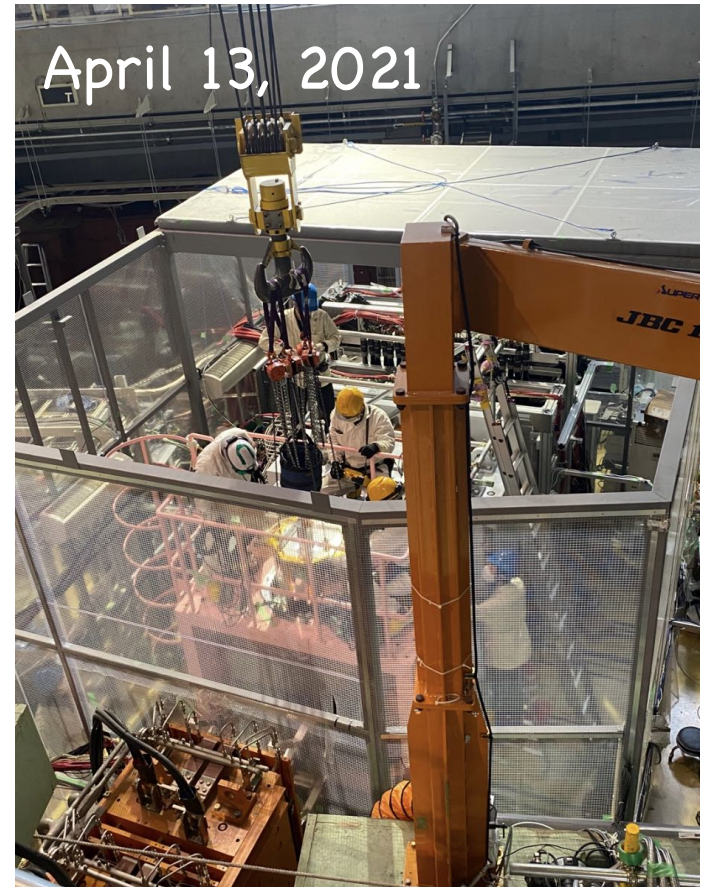
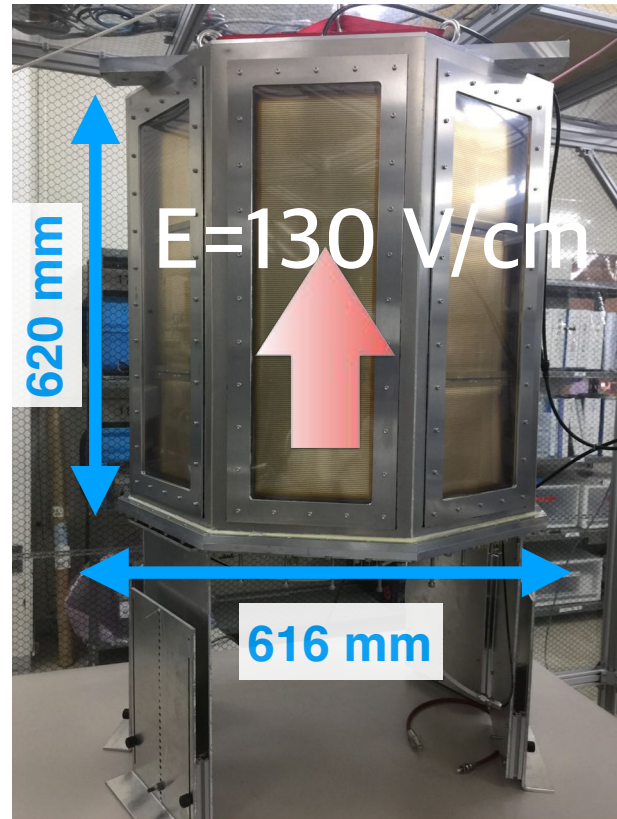
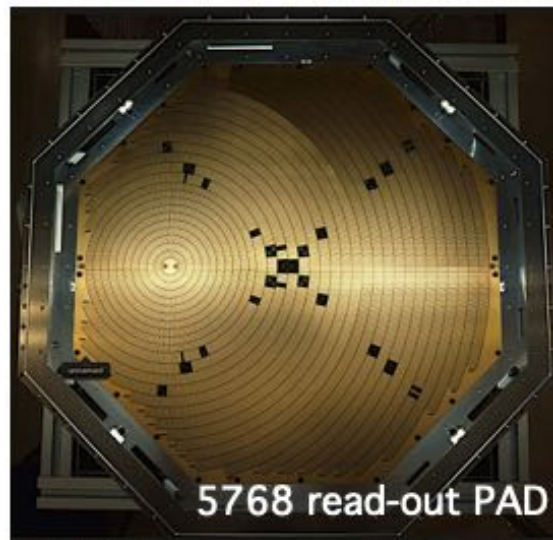
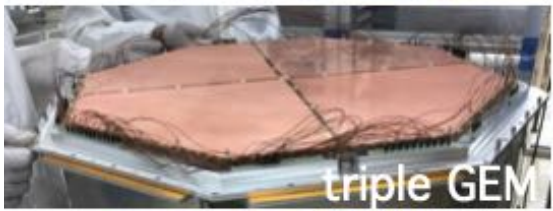
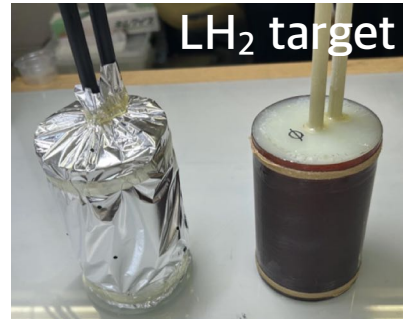
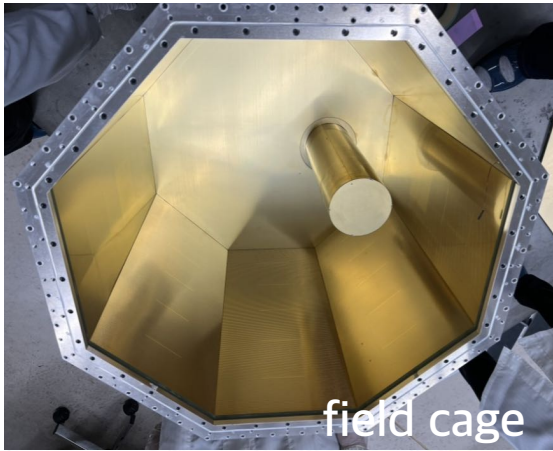
- ▶ Large acceptance ($\sim 4\pi$)
- ▶ High rate capability ($\sim 10^6$ cps)
- ▶ High resolution ($\sigma \sim 1$ MeV)

1 M/spill (2s)
 π^\pm beam

HypTPC

▶ *Hyperon Spectrometer*

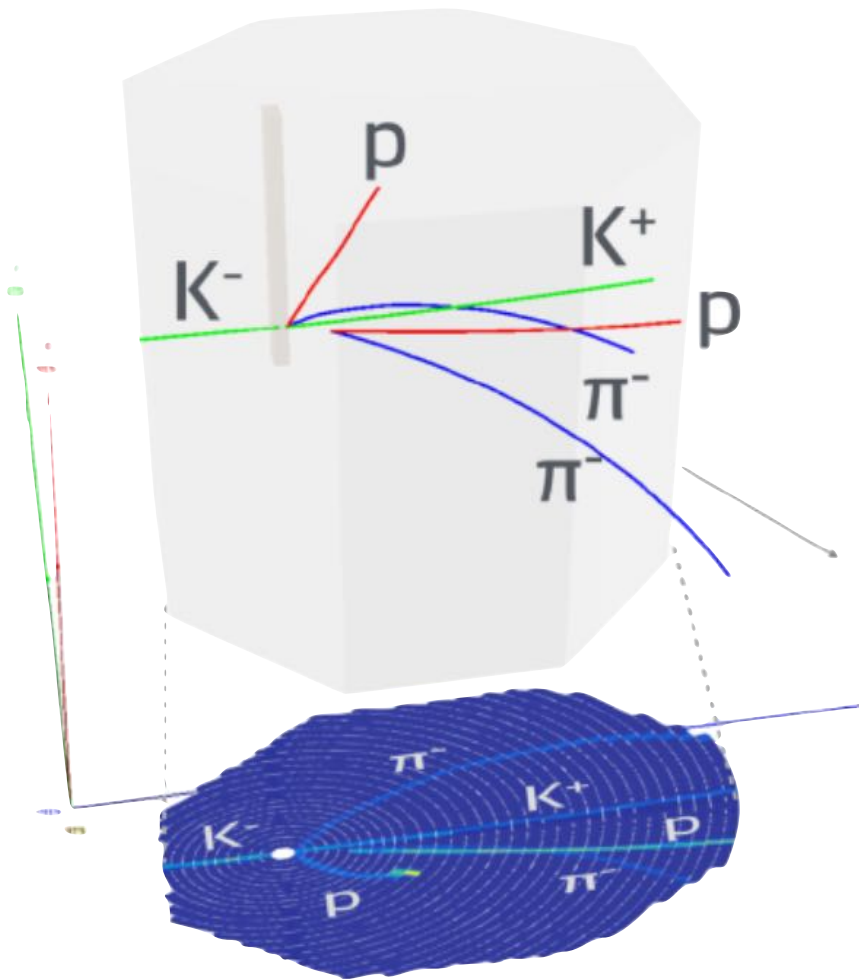
Hyperon Spectrometer



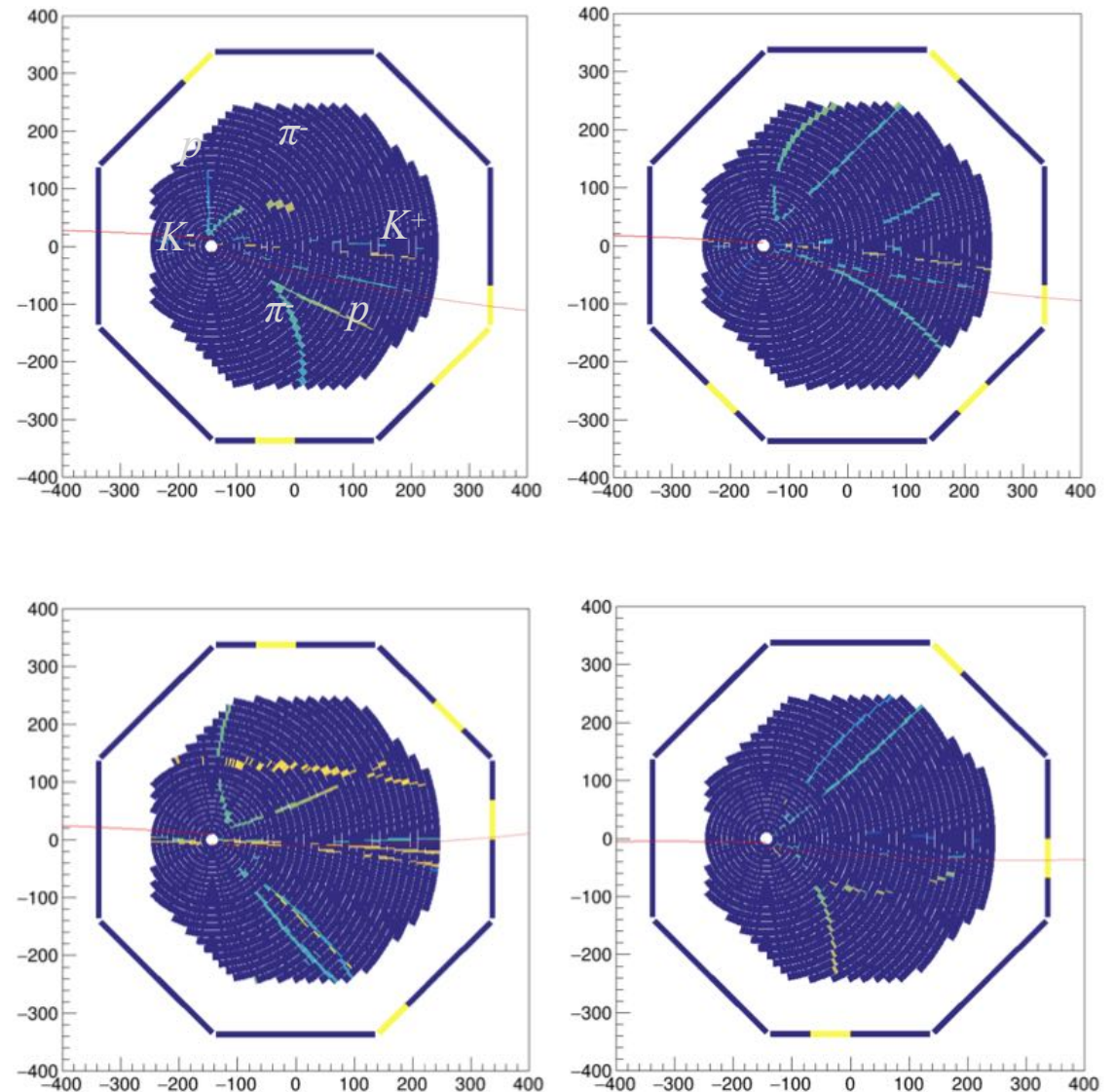
► *HypTPC*

Hyperon Spectrometer

▶ *Simulation (J-PARC E42)*



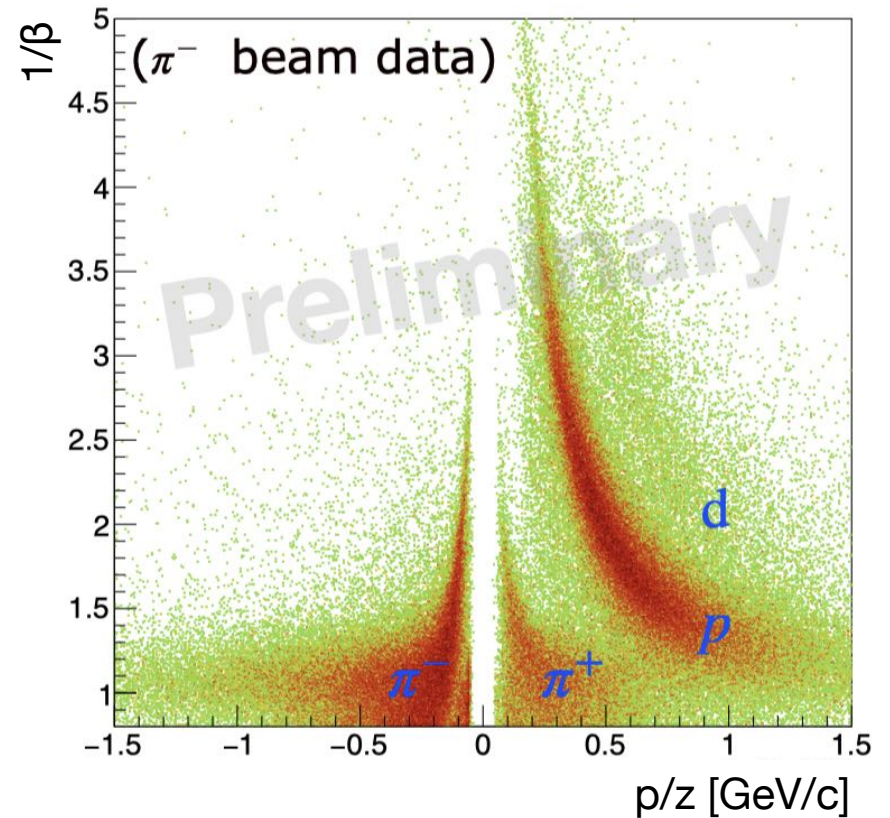
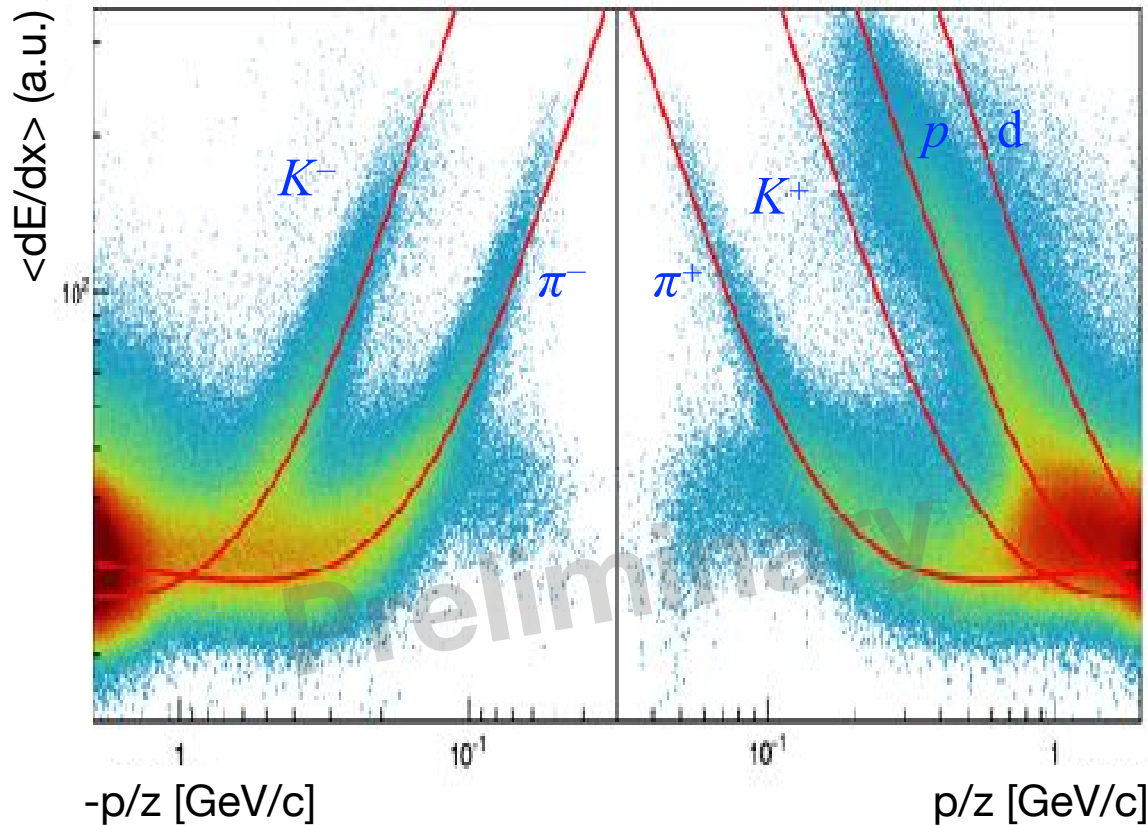
▶ *Event Display (J-PARC E42)*



PID by Hyperon Spectrometer

- ▶ HypTPC dE/dx
 - $\sigma_{\langle dE/dx \rangle} / \langle dE/dx \rangle \sim 20\%$
at $0.4 < p_T < 0.45$ GeV/c

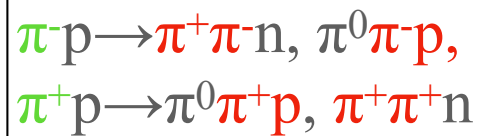
- ▶ HTOF Time-of-Flight
flight length: 200~500 mm
 $\sigma_t \sim 120$ ps for π^-



J-PARC E45 Multiplicity Trigger

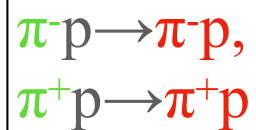
- ▶ Trigger: **HTOF multiplicity-2** from $\pi^\pm p$ reactions at 1.5 - 2.15 GeV ($p=0.73 - 2.0$ GeV/c)

- ▶ $\pi p \rightarrow \pi\pi N$ reactions

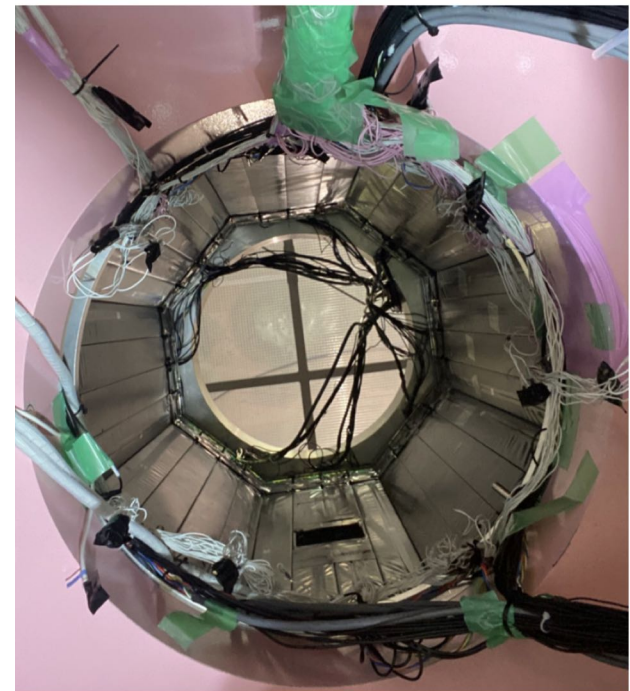
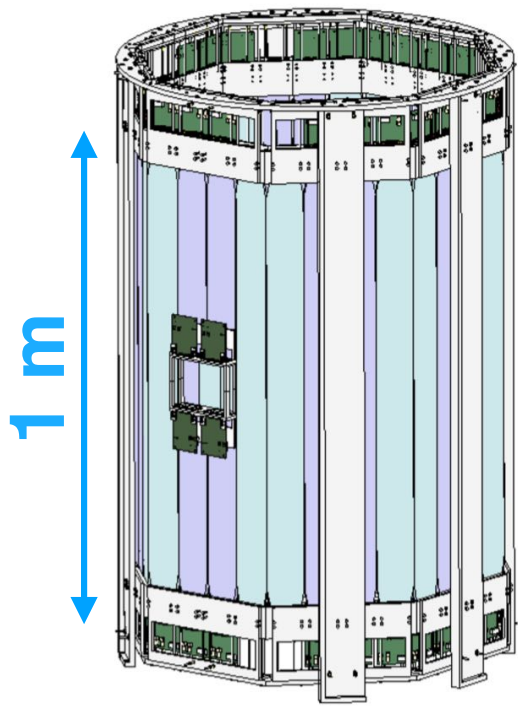
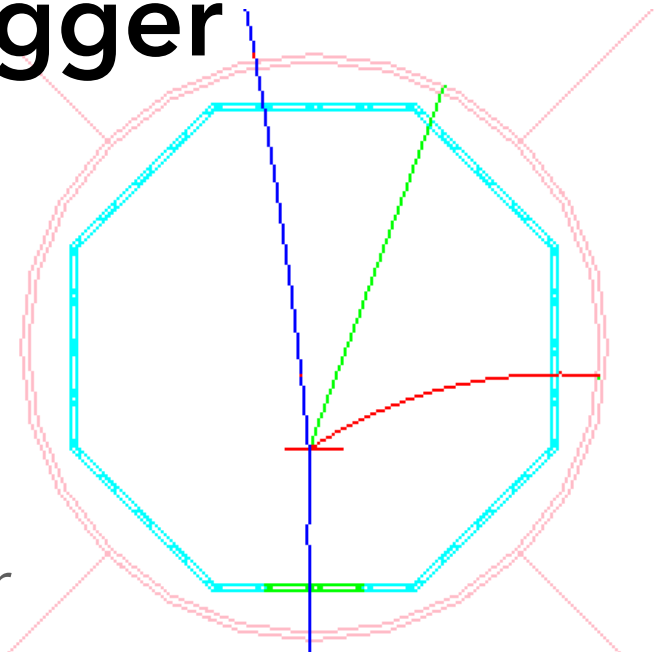


- ▶ *HTOF detector*

- ▶ $\pi p \rightarrow \pi p$ reactions



- ▶ $\pi p \rightarrow KY$ reactions



E45 Yield Estimation and Run Plan

$$N = \sigma \times \frac{\rho \times L \times N_A}{A} \times N_{beam} \times Acc,$$

π^\pm Beam: $N_{beam}=1$ M/spill

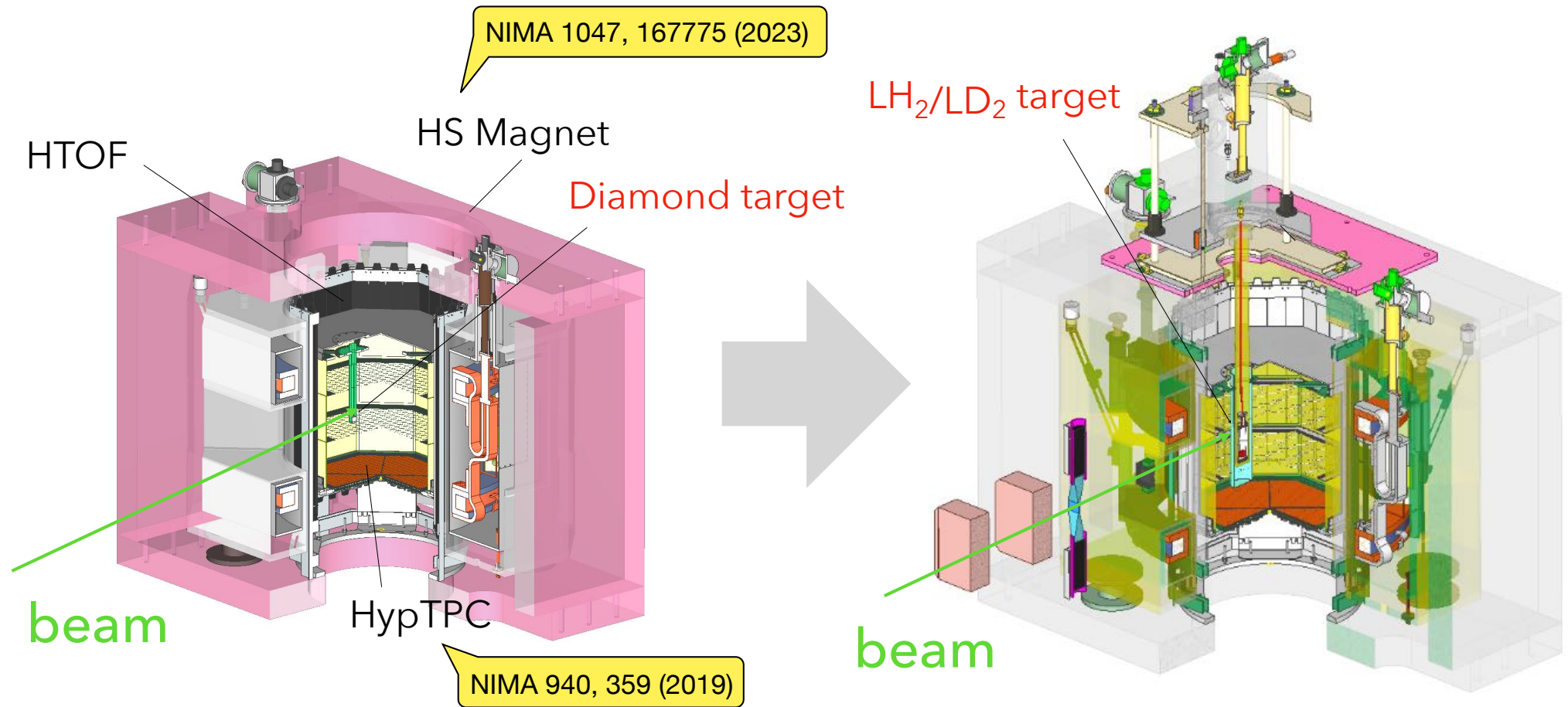
LH₂ Target: $\rho L=0.45$ g/cm² ($\phi 8$ cm), $N_A=6.022 \times 10^{23}$, $A=1$

Detector Acceptance: $Acc=0.4$

- ▶ $\sigma \sim 2$ mb ($\pi^+ p \rightarrow \pi^+ \pi^+ n$) $\rightarrow N \sim 220$ events / spill (5.2s)
In order to achieve $\sim 30k$ events/bin with
 24 energy bins (1.50 - 2.15 GeV) $\times 20$ angle bins
 $\rightarrow \sim 4$ hours for each beam energy setting is required.
- ▶ Considering all $\pi\pi N$ reactions with both π^\pm beams,
a total of 15 -day beam time is required.

Current Preparation Status

HypTPC Upgrade



E42

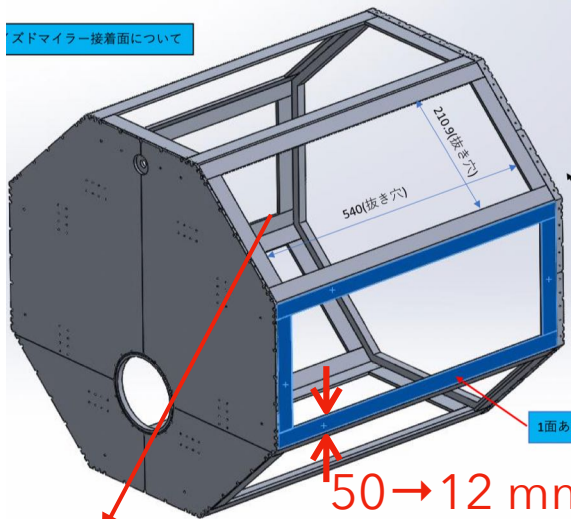
May-Jun 2021

E45/E72/(E90)

HypTPC Upgrade

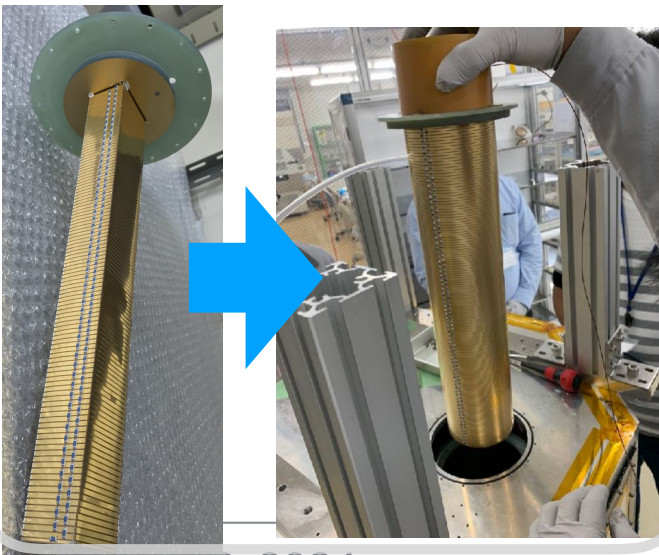
▶ Gas Vessel

ズドマイラー接着面について

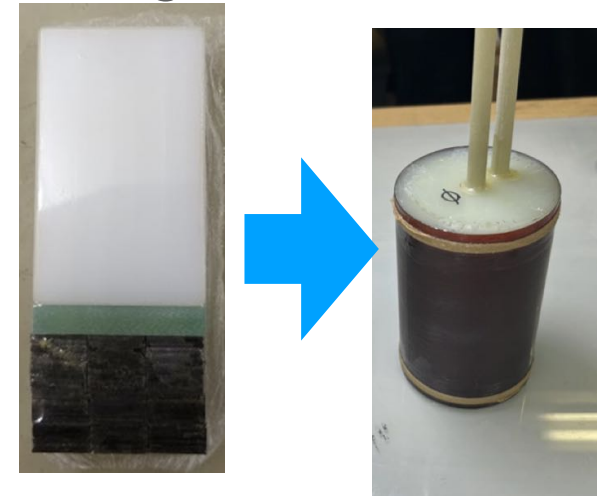


50→12 mm
Mylar → Aluminum Mylar

▶ Target holder



▶ Target



Target cooling/moving system

Simulation Study for the Trigger

→ Main Trigger: Beam \otimes HTOF-Mp2

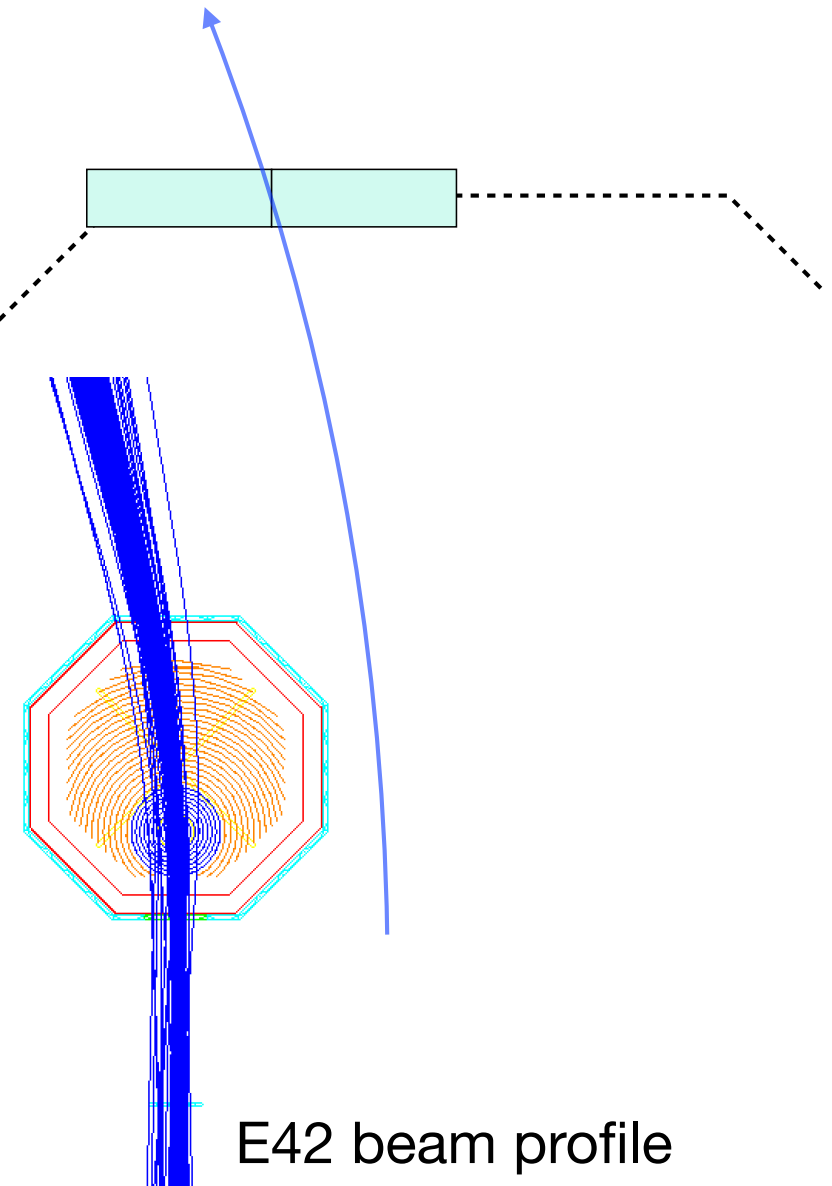
→ Beam background?

Geant4 simulation: $\sim 0.7\%$ in 1 M/spill

→ 7k/spill

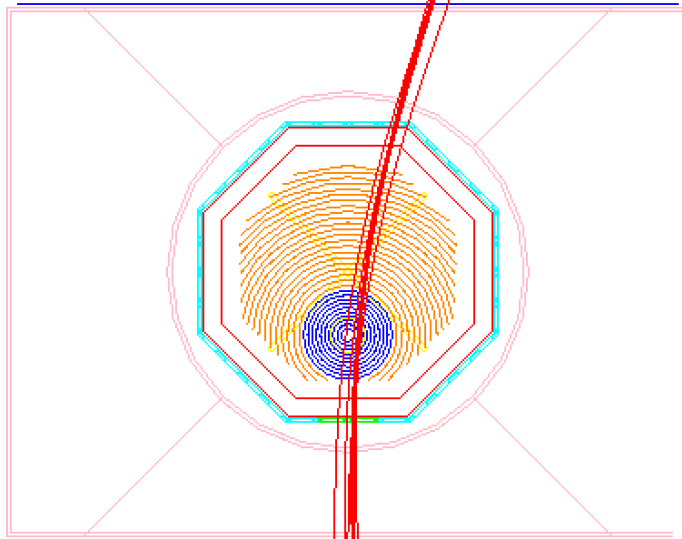
→ Max. allowable trigger rate: ~ 3 k/spill

→ Beam veto method is under consideration.



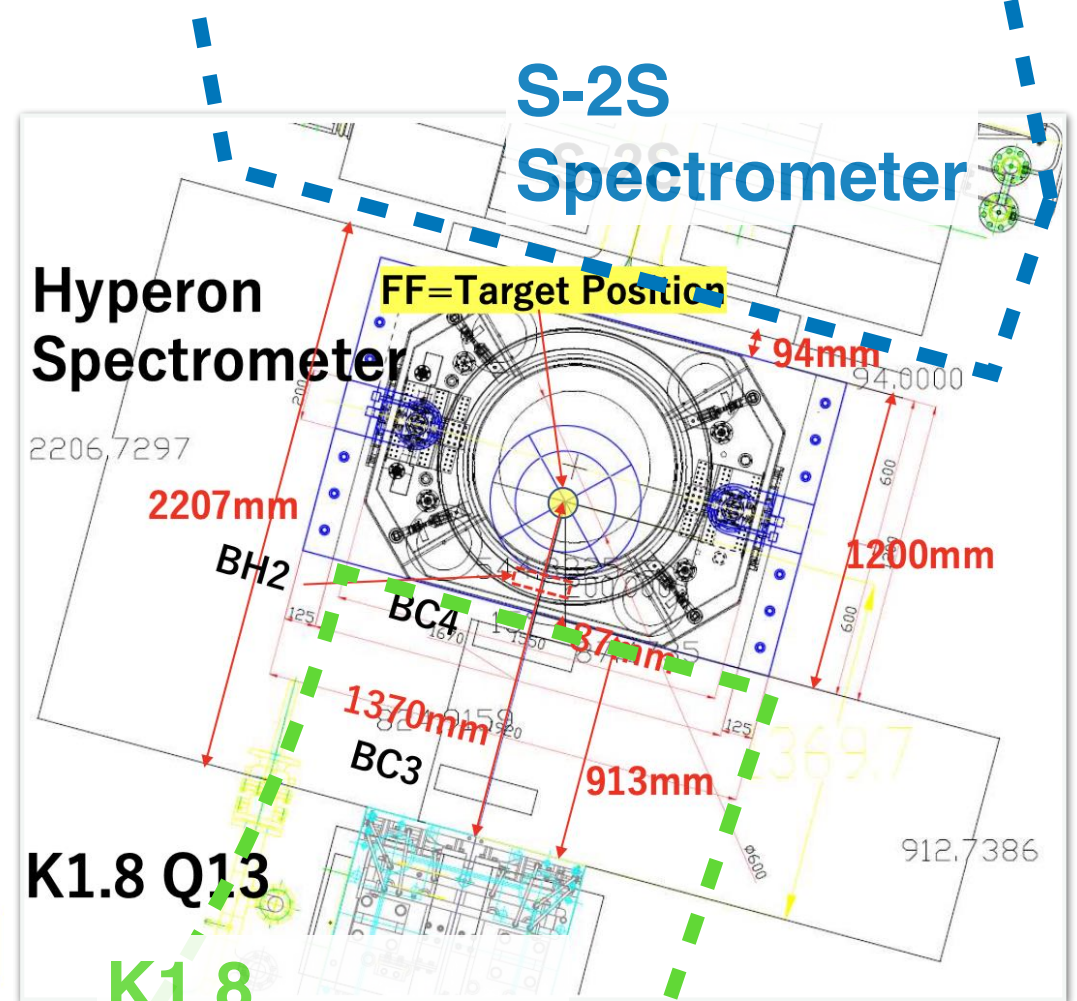
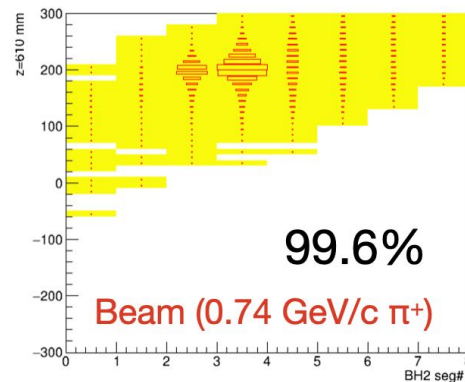
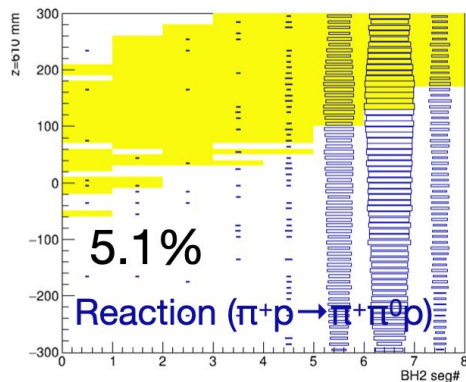
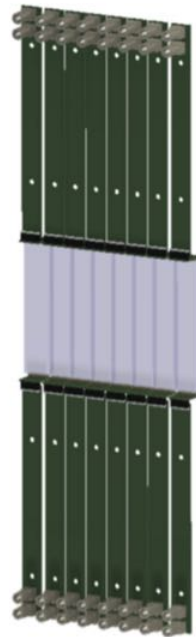
Beam Veto Counters?

VP3: z=+610 mm



BH2: z=-640 mm

VP0: z=-1100 mm



Expected E45 Experimental Setup
@K1.8 Beam Line

Summary

- The N^* spectrum is a long-standing problem, and the 3-body hadronic reaction data are required for the dynamical coupled-channels calculation.
- The J-PARC E45 will open a unique opportunity to study the N^* resonances in $\pi p \rightarrow \pi\pi N$ and KY reactions in $E_{\text{CM}} = 1.5 - 2.15 \text{ GeV}$.
- We are currently preparing the detectors for the experiment, and we anticipate the beam time around 2026.

Thursday 15:45-17:05
Discussion Session for
Exploring Excited Nucleons

Discussion Session -- Exploring Excited Nucleons
Philip Cole et al.

Bootham and Micklegate Suite, Hilton Hotel York 15:45 - 17:05