

Oct 19-23, 2026

Study of Nucleon Resonances in Pion-Induced Reactions at J-PARC E45

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for the J-PARC E45 Collaboration

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E45

J-PARC HypTPC Collaboration

Missing Resonance Problem

PDG 2026: Baryon listings

N	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	****
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	***
$N(1895)$	$1/2^-$	****
$N(1900)$	$3/2^+$	****
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	***
$N(2100)$	$1/2^+$	***
$N(2120)$	$3/2^-$	***

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	****
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	***
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*

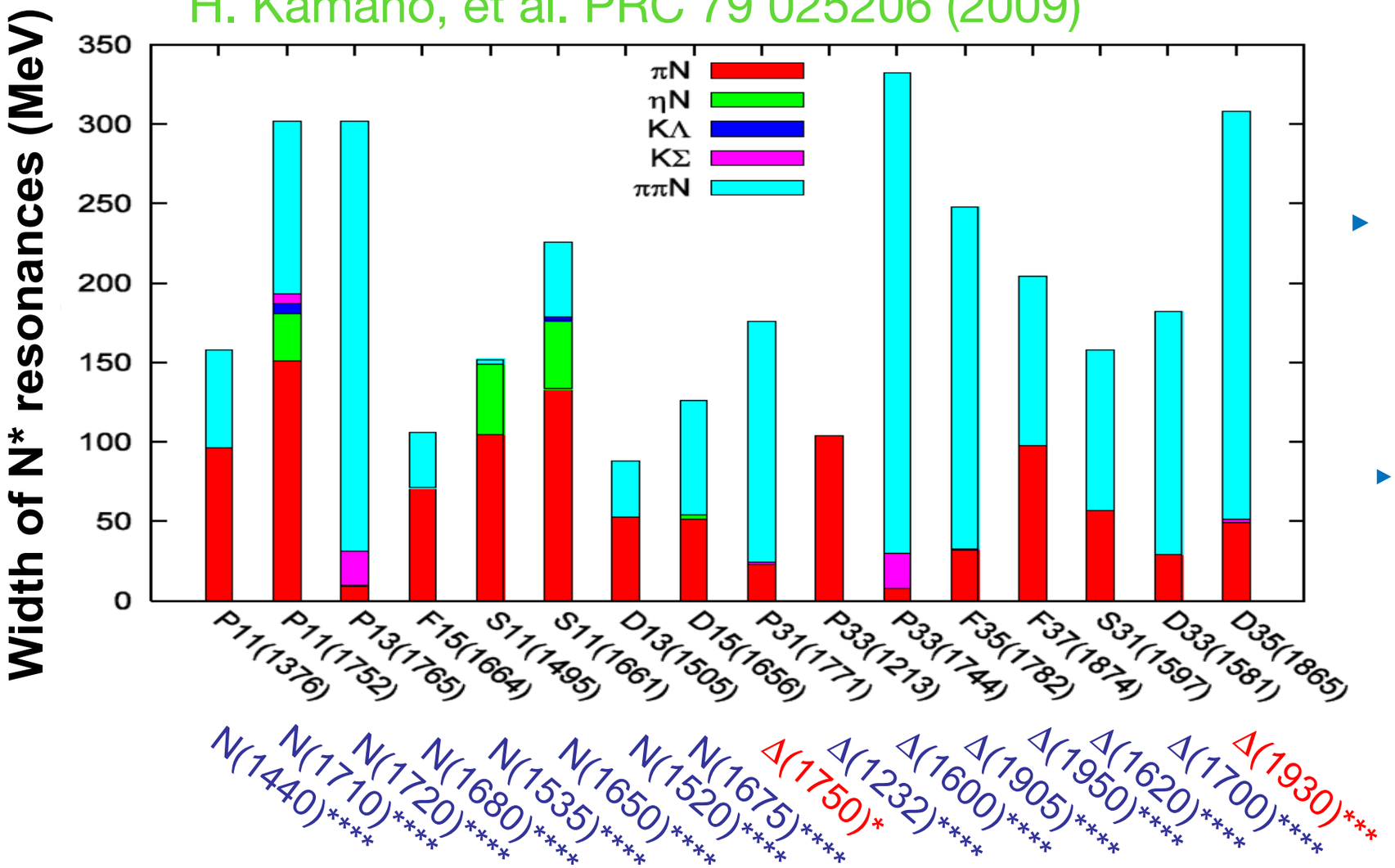
**** Established
***
* **

- Many low-lying N* and Δ* resonances are well established, while many higher-mass states remain uncertain.
- Higher-mass resonances are often broad, strongly overlap, and couple to multiple final states.
- A coupled-channel partial-wave analysis (PWA) requires complementary data from hadronic and electromagnetic reactions.

Importance of ππN Decay

- Dynamical coupled-channel calculations predict large ππN decay widths for many N* and Δ* resonances.

H. Kamano, et al. PRC 79 025206 (2009)



- Intermediate states:
  - N* → πΔ, ρN, σN
  - Δ* → πΔ, ρN
- All lead to the same ππN final state

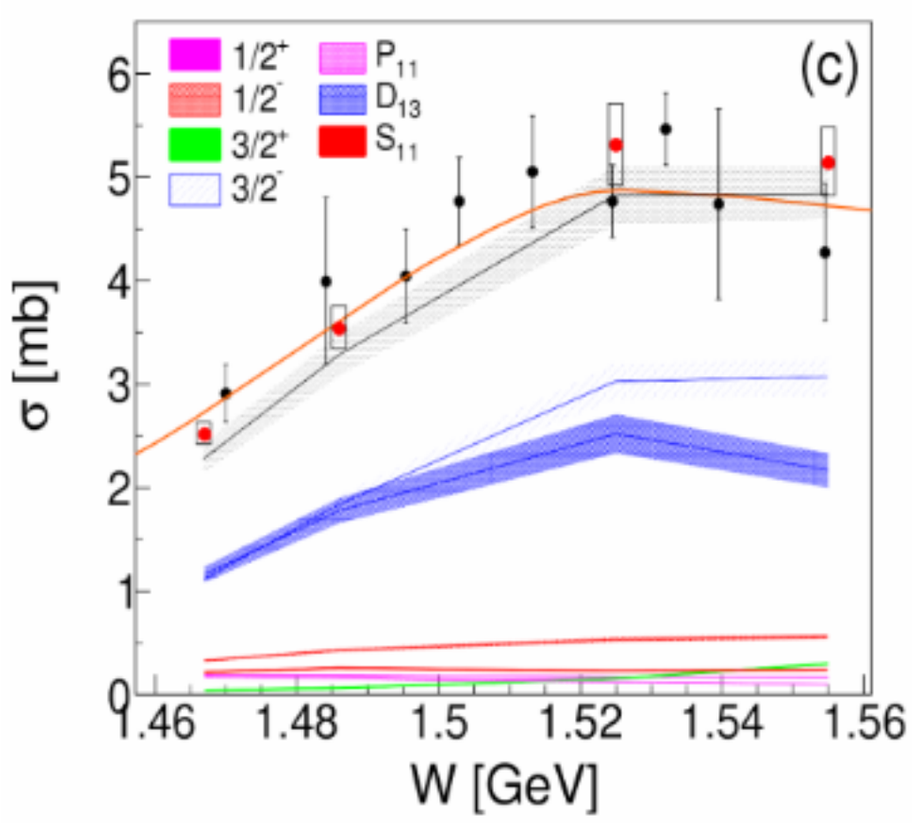
Invariant-mass and angular distributions help disentangle these contributions and their interference.

HADES: Exclusive $\pi\pi$N Measurements

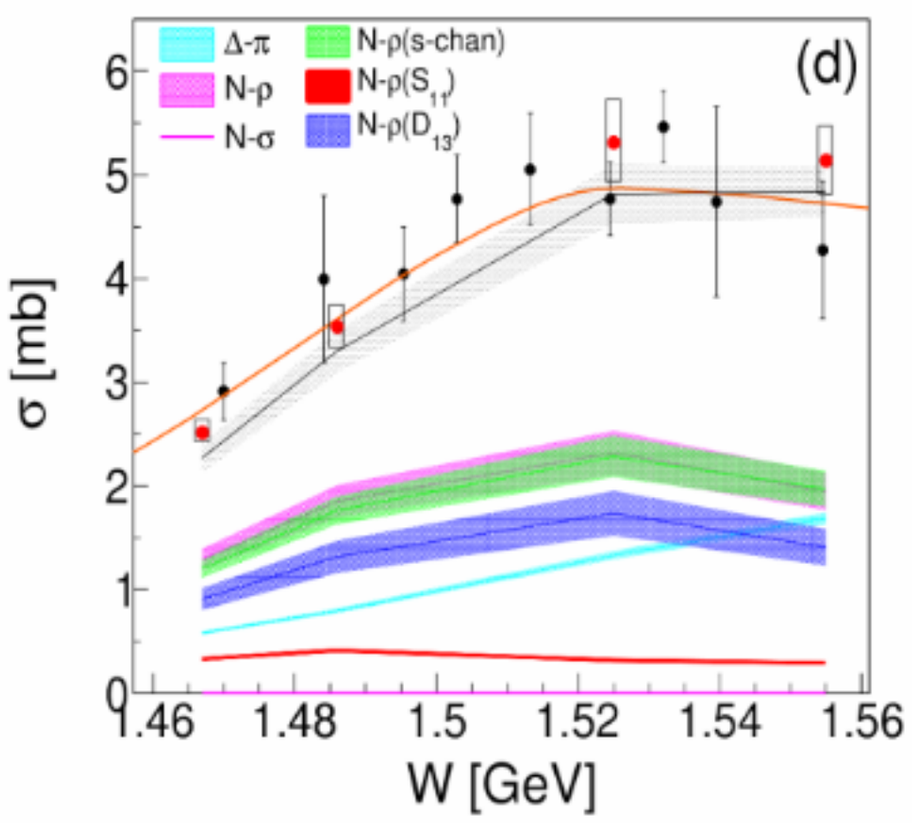
- HADES measured $\pi^- p \rightarrow \pi\pi N$ in the second resonance region.
- An event-by-event PWA uses invariant-mass and angular correlations.
- The combined fit extracts partial wave and intermediate-state contributions.

$\pi^- p \rightarrow \pi^- \pi^0 p$, W ≈ 1.47–1.55 GeV

Partial-wave contributions



Intermediate-state contributions



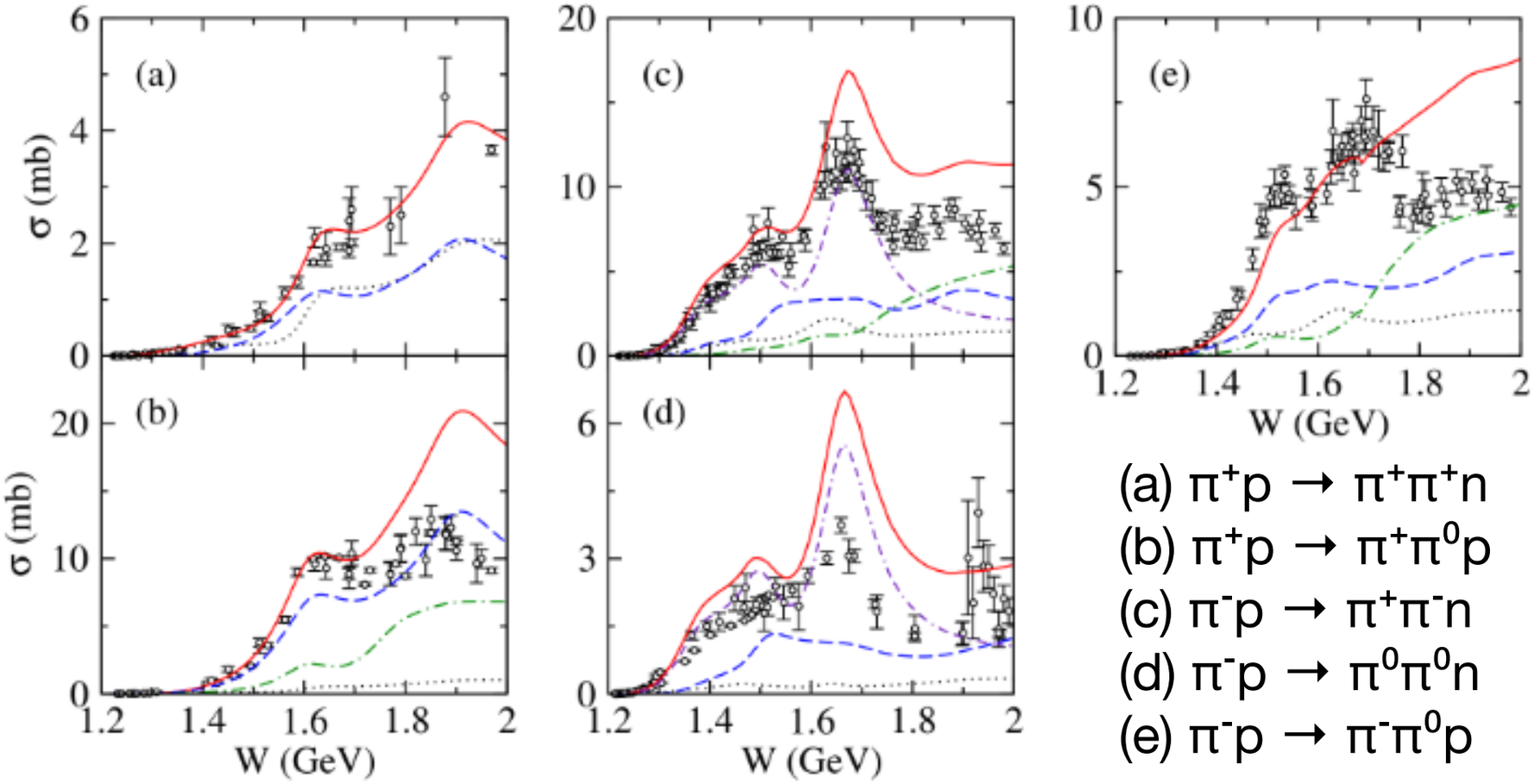
world data · HADES data — PWA Manley ▒ PWA Bn-Ga

HADES, Phys. Rev. C 102, 024001 (2020)

ANL-Osaka: $\pi N \rightarrow \pi\pi N$ Predictions

- The ANL–Osaka dynamical coupled-channel model predicts ππN production and the amplitudes are constrained by two-body πN and γN reaction data.
- The predictions overestimate several channels at higher energies.

H. Kamano and T.-S. H. Lee, arXiv:2601.17389 (2026)



Two-body data alone do not fully constrain the ππN decay amplitudes in this model

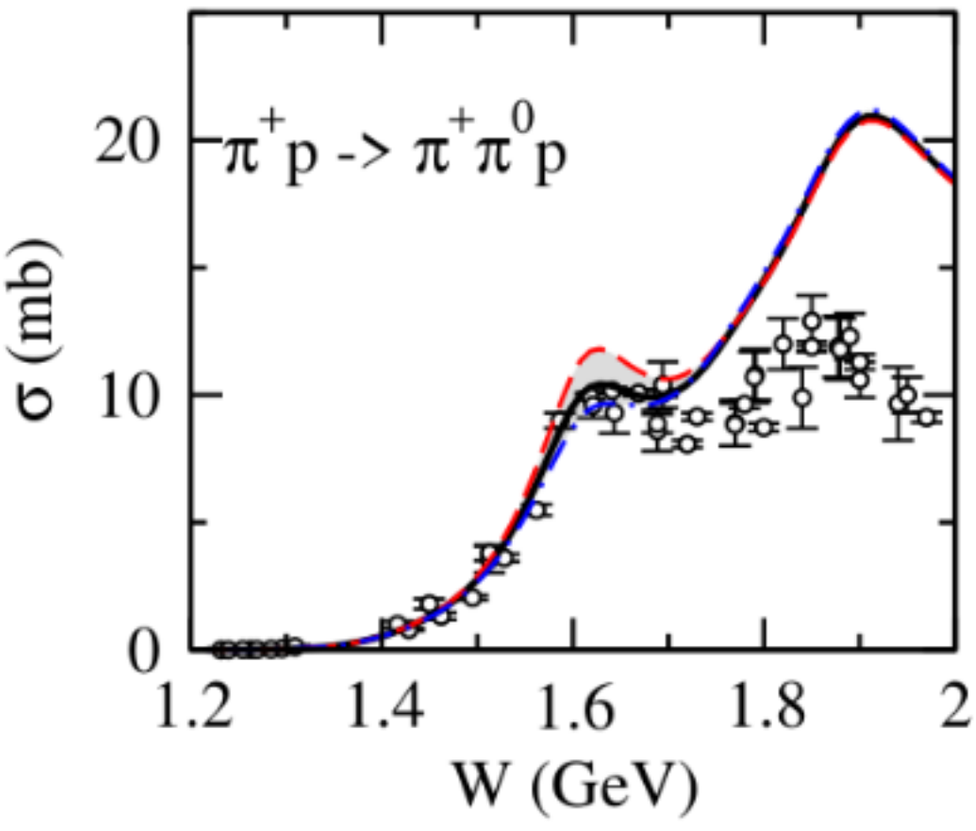
Sensitivity to Decay Amplitudes

H. Kamano and T.-S. H. Lee, arXiv:2601.17389 (2026)

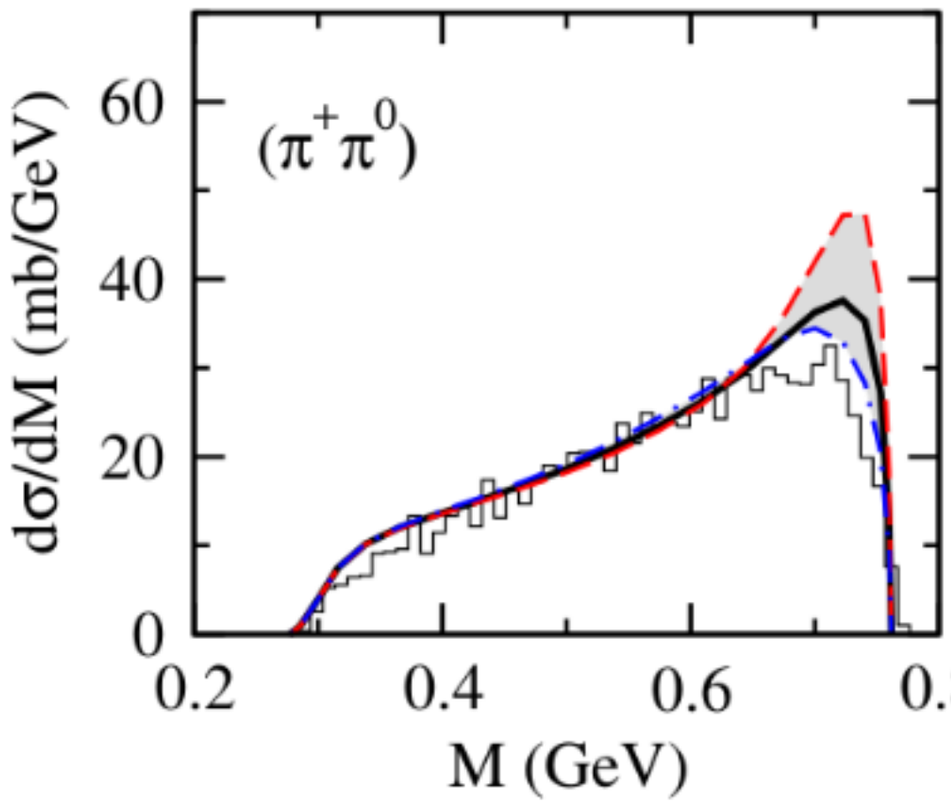
Example: $\pi^+ p \to \pi^+\pi^0 p$

$S_{31} \to \rho N$: dressed decay vertex varied by ±50%

Total cross section vs W



$M(\pi^+\pi^0)$ at W = 1.70 GeV

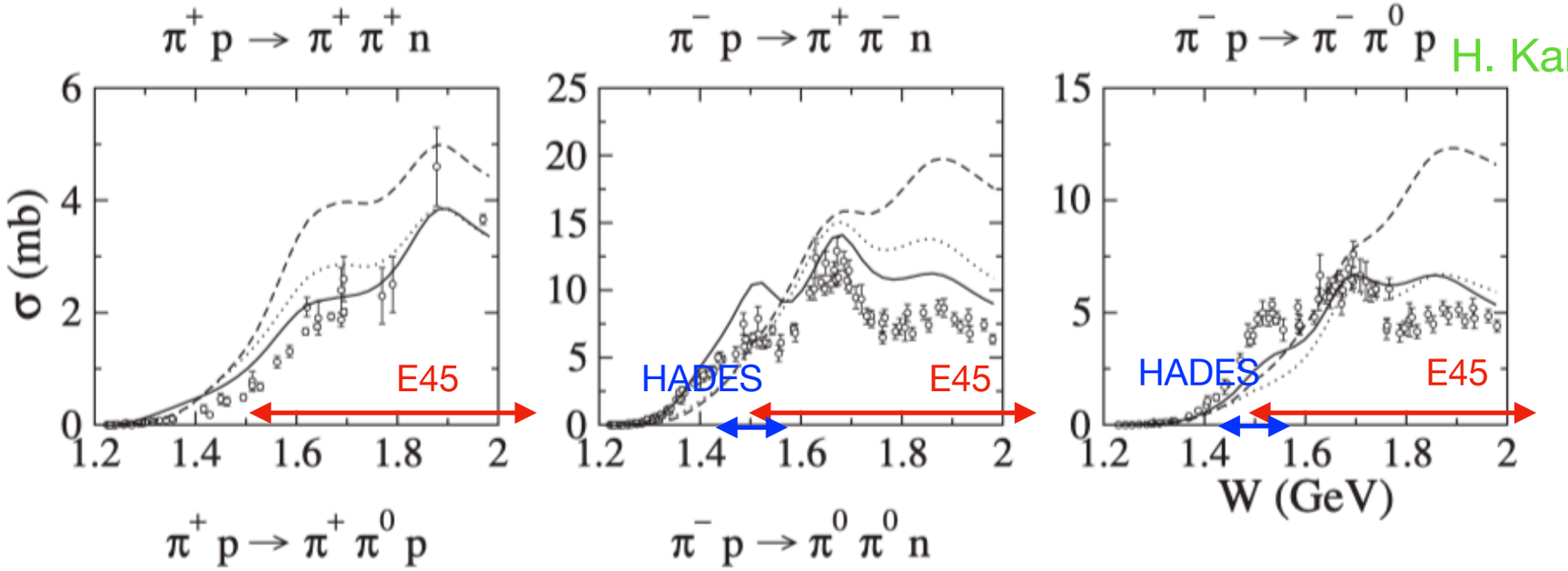


Black curve: baseline
Red: +50%
Blue: -50%

Invariant-mass distributions constrain decay amplitudes beyond total cross sections.

J-PARC E45: N*/Δ* Baryon Spectroscopy

- *N**/Δ* spectroscopy through $\pi^{\pm}p \rightarrow \pi\pi N$ over the wide energy range of W=1.5 - 2.15 GeV (p=0.73 - 2.0 GeV/c) using high intensity beam at J-PARC.
- Goal: Updates on the world database ($\pi p \rightarrow \pi\pi N$)
  - 240k events measured in 1970's → ×100 higher statistics

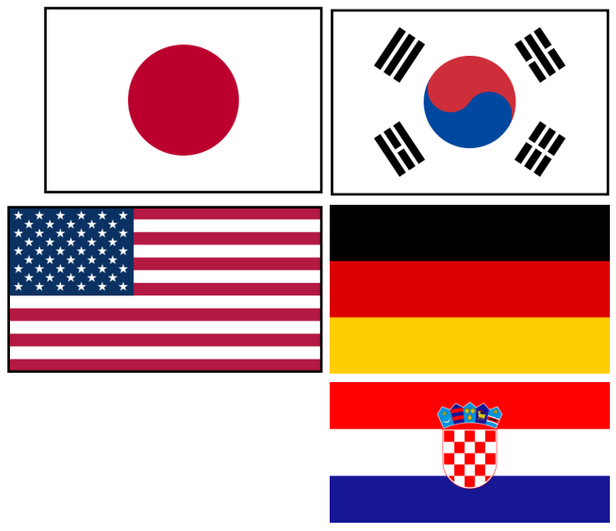


H. Kamano et al., PRC 79, 025206 (2009)
HADES, PRC 102, 024001 (2020)

- Wider energy coverage
- Wider angular coverage
- Both π- and π+ beams
  - π^-p: I=1/2 or 3/2
  - π^+p: I=3/2

J-PARC E45 Collaboration *co-spokespersons

H. Sako, K. Imai, S. Hasegawa, S. Sato, K. Tanida, T. Hashimoto	(Japan Atomic Energy Agency)
P. Cole	(Lamar Univ.)
S.H. Kim, J.J. Lee, J.H. Park	(Kyungpook National University)
K. Joo, S. Diehl, A. Kim. U. Shrestha, R. Capobianco, V. Klimenko, J. Richards, N. Trotta, T. Hayward, P. Simmerling, R. Santos	(Univ Connecticut)
C. Djalali	(Ohio Univ.)
J.K. Ahn, W.S. Jung, S.B. Yang, B.M. Kang, S.W. Choi, H.I. Lee, S.J. Lee	(Korea Univ.)
S. Nakamura, M. Niiyama	(Kyoto Univ.)
H. Fujioka	(Tokyo Inst. Tech.)
T. Takahashi, K. Ozawa, H. Sugimura	(KEK)
K. Nakazawa, H. Ekawa	(RIKEN)
S. H. Hwang	(KRISS)
Y. Ichikawa, S. Hayakawa, J. Yoshida	(Tohoku Univ.)
W. J. Briscoe, M. Doering, I. Strakovsky, R. Workman	(George Washington Univ.)
L. Guo	(Florida International Univ.)
T.S.-H. Lee	(Argonne National Lab.)
T. Sato, Y. Nakada	(Osaka Univ.)
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 (**J**apan **P**roton **A**ccelerator **R**esearch **C**omplex)

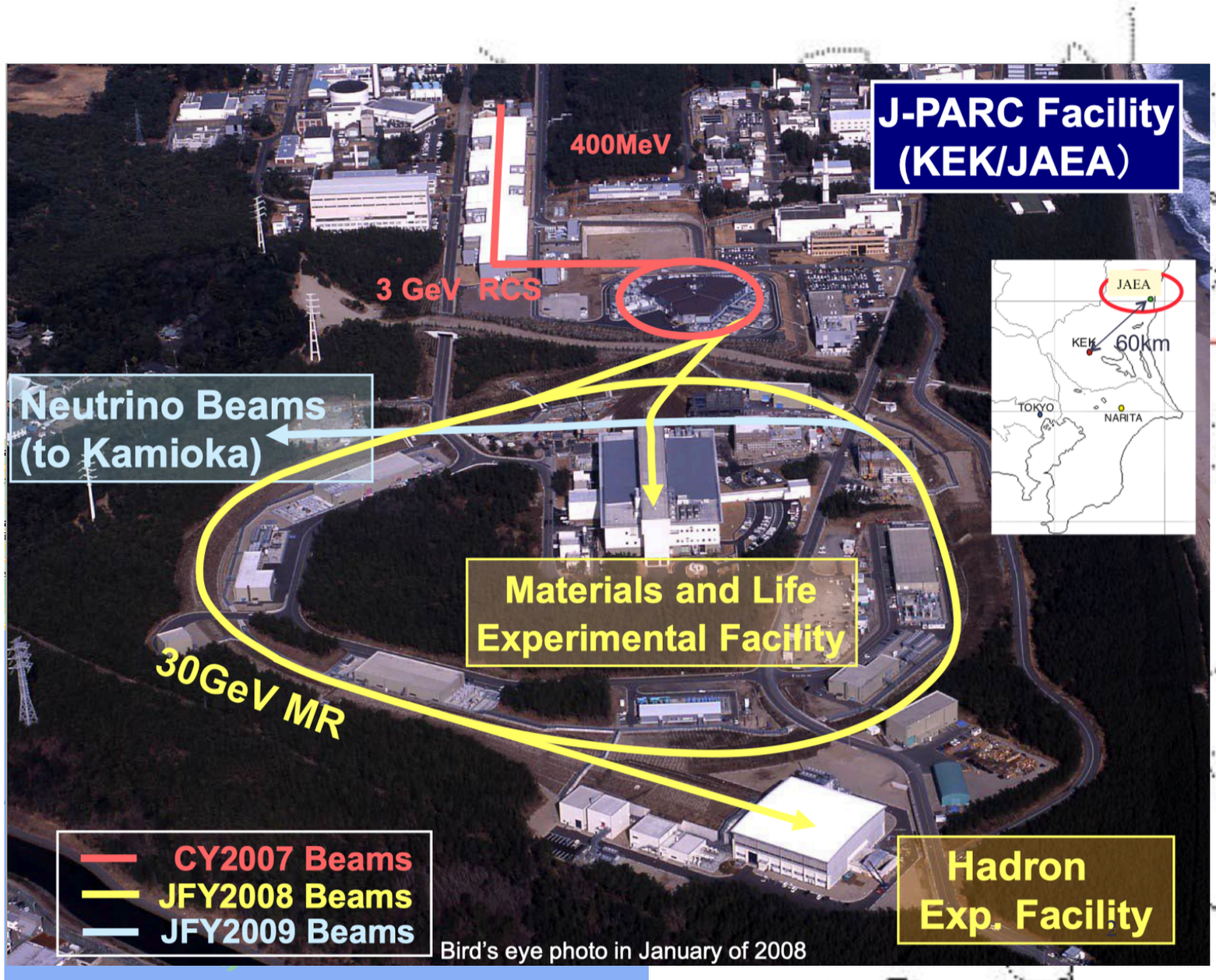
- the world's top class high-energy and high-intensity proton beam

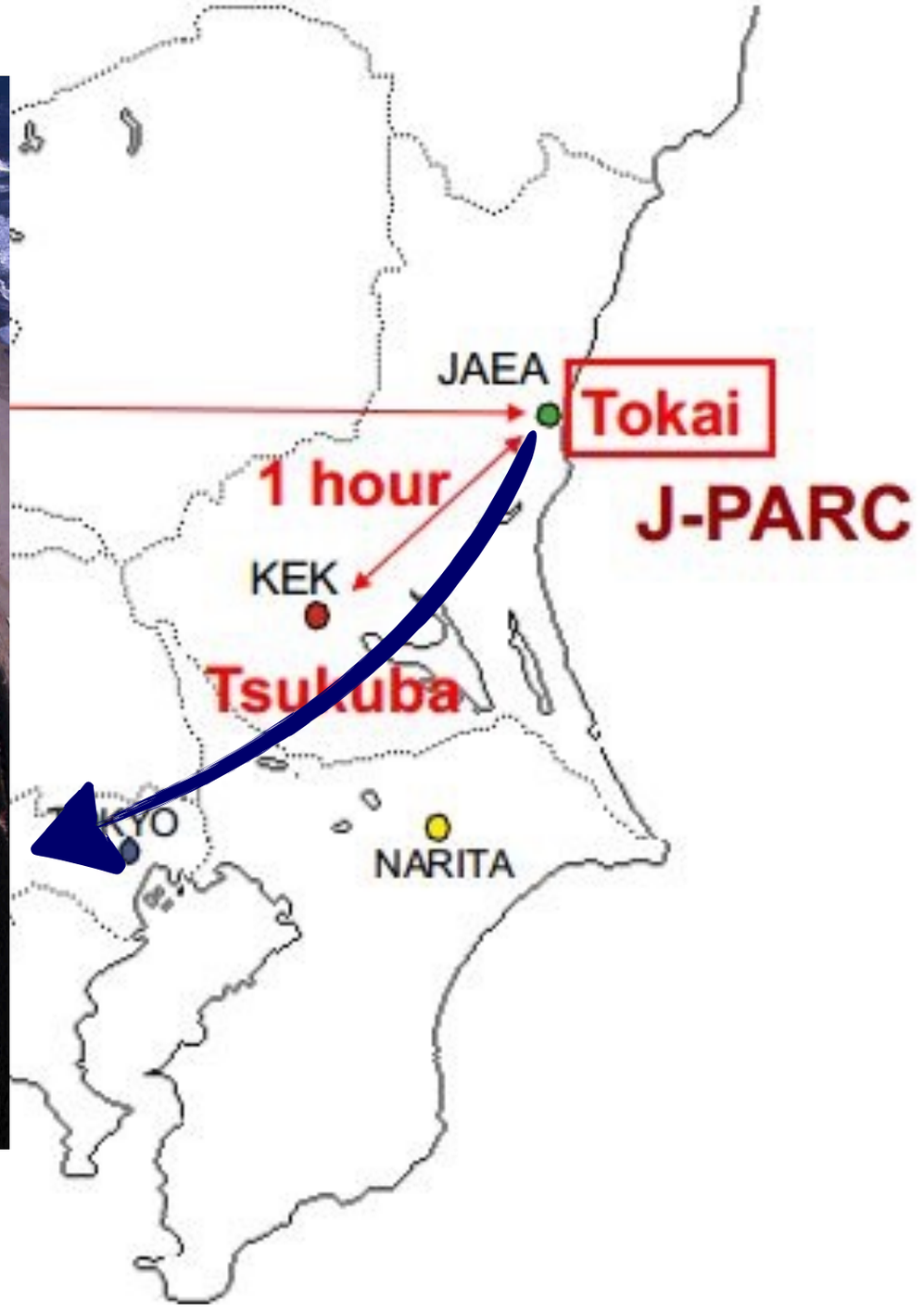


Joint Project between JAEA & KEK

J-PARC (**J**apan **P**roton **A**ccelerator **R**esearch **C**omplex)

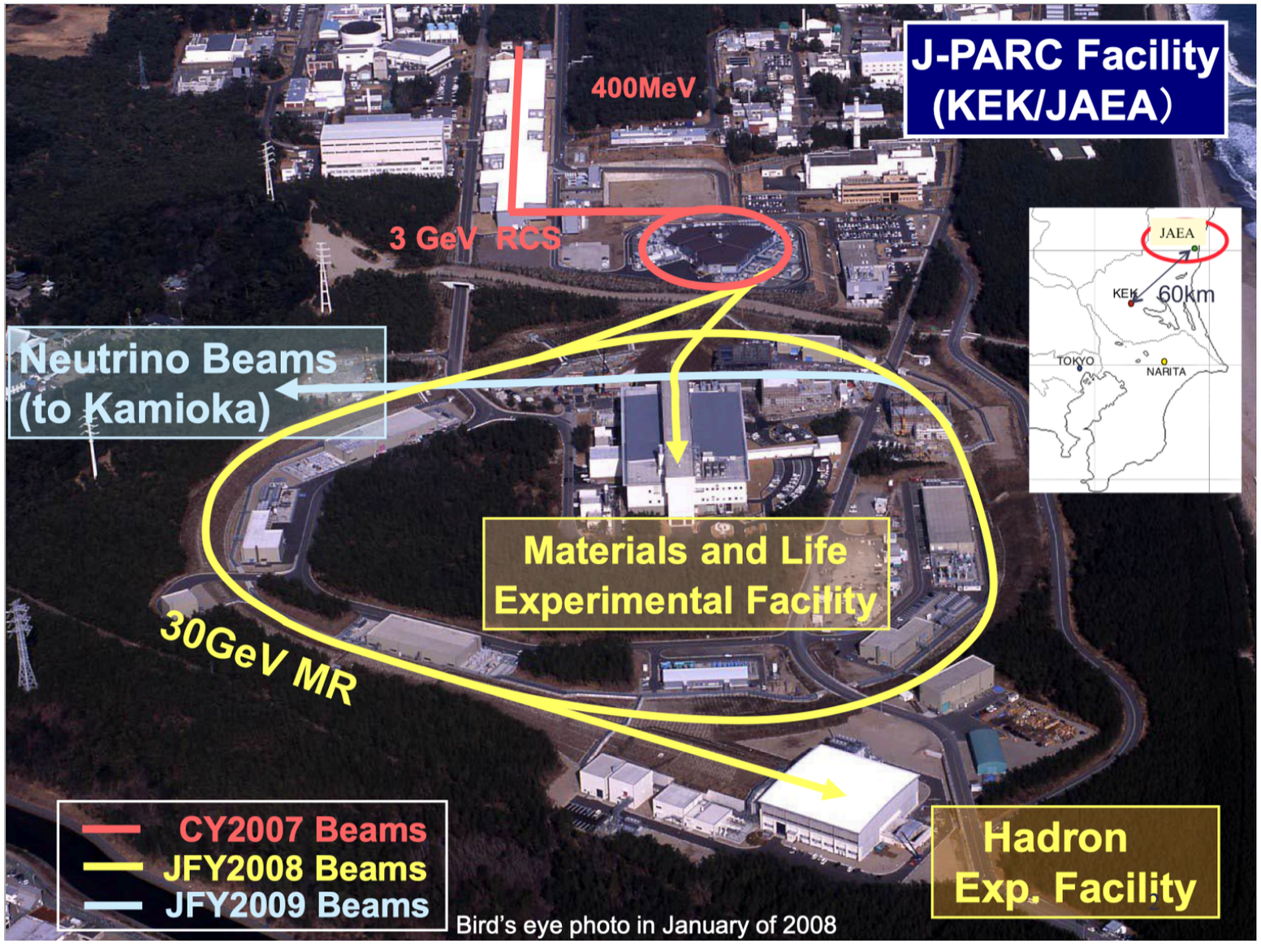
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Joint Project between JAEA & KEK

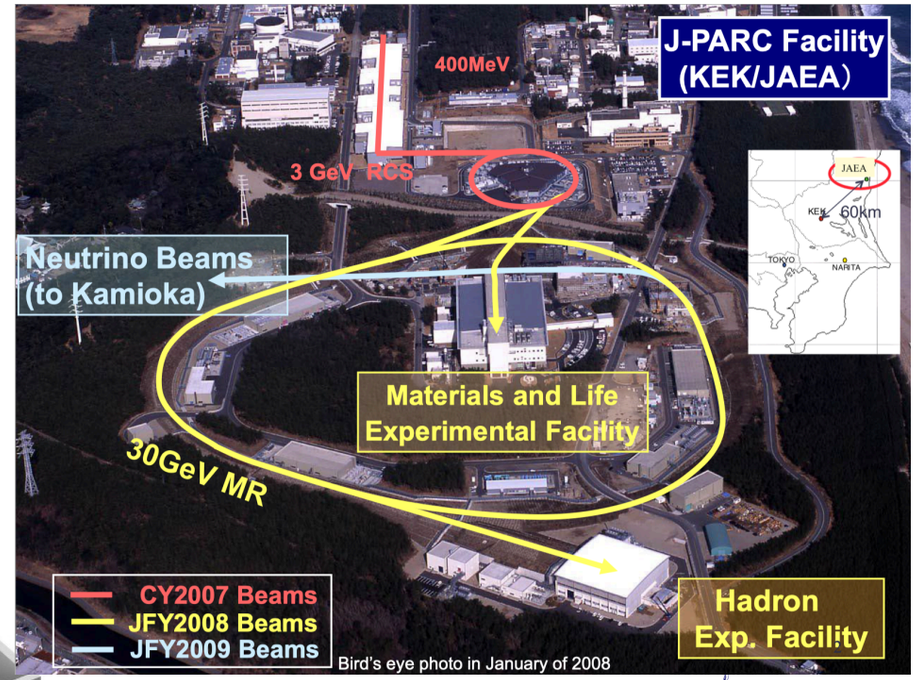
J-PARC Hadron Experimental Facility

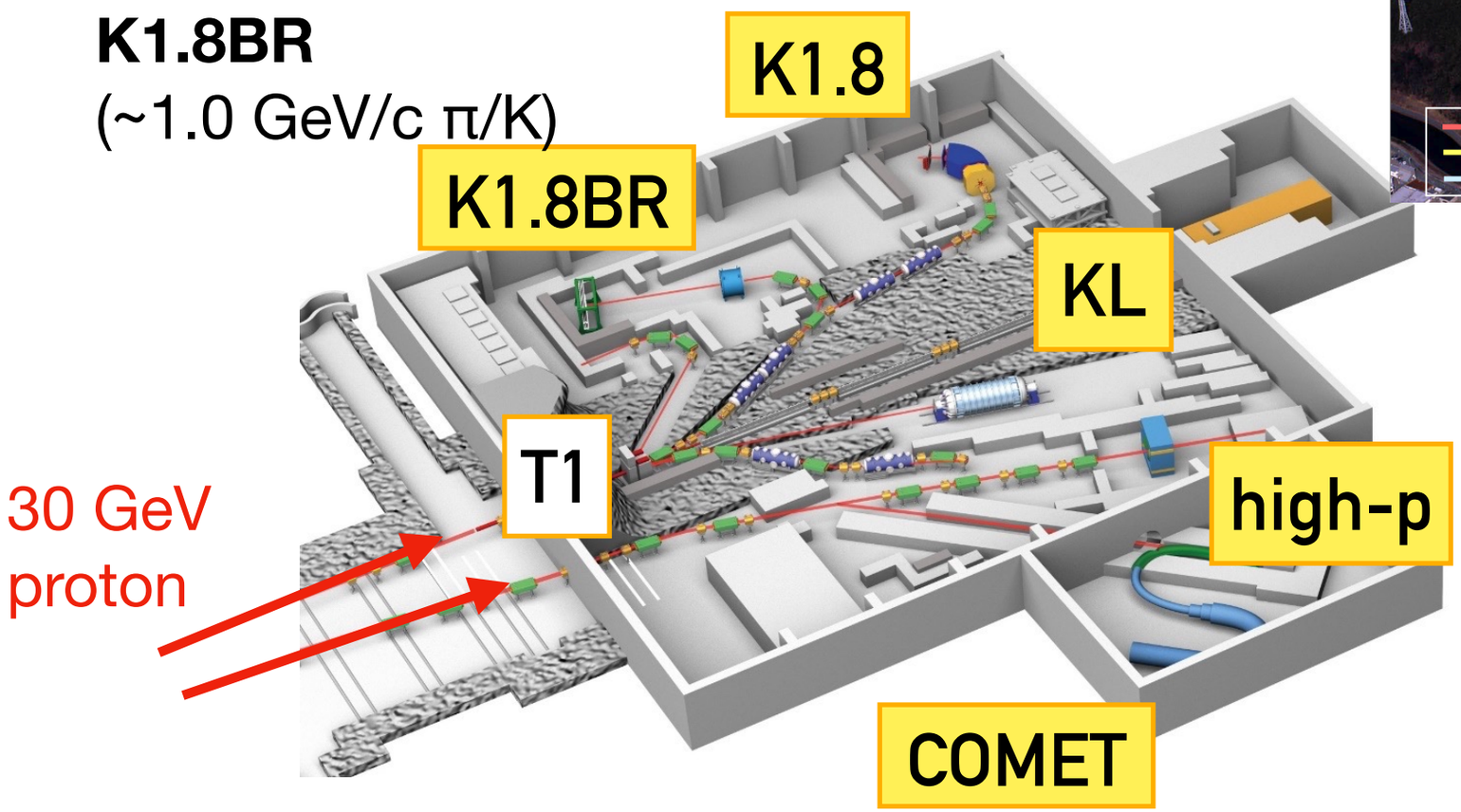


J-PARC Hadron Experimental Facility

K1.8
(~1.8 GeV/c π/K)

K1.8BR
(~1.0 GeV/c π/K)

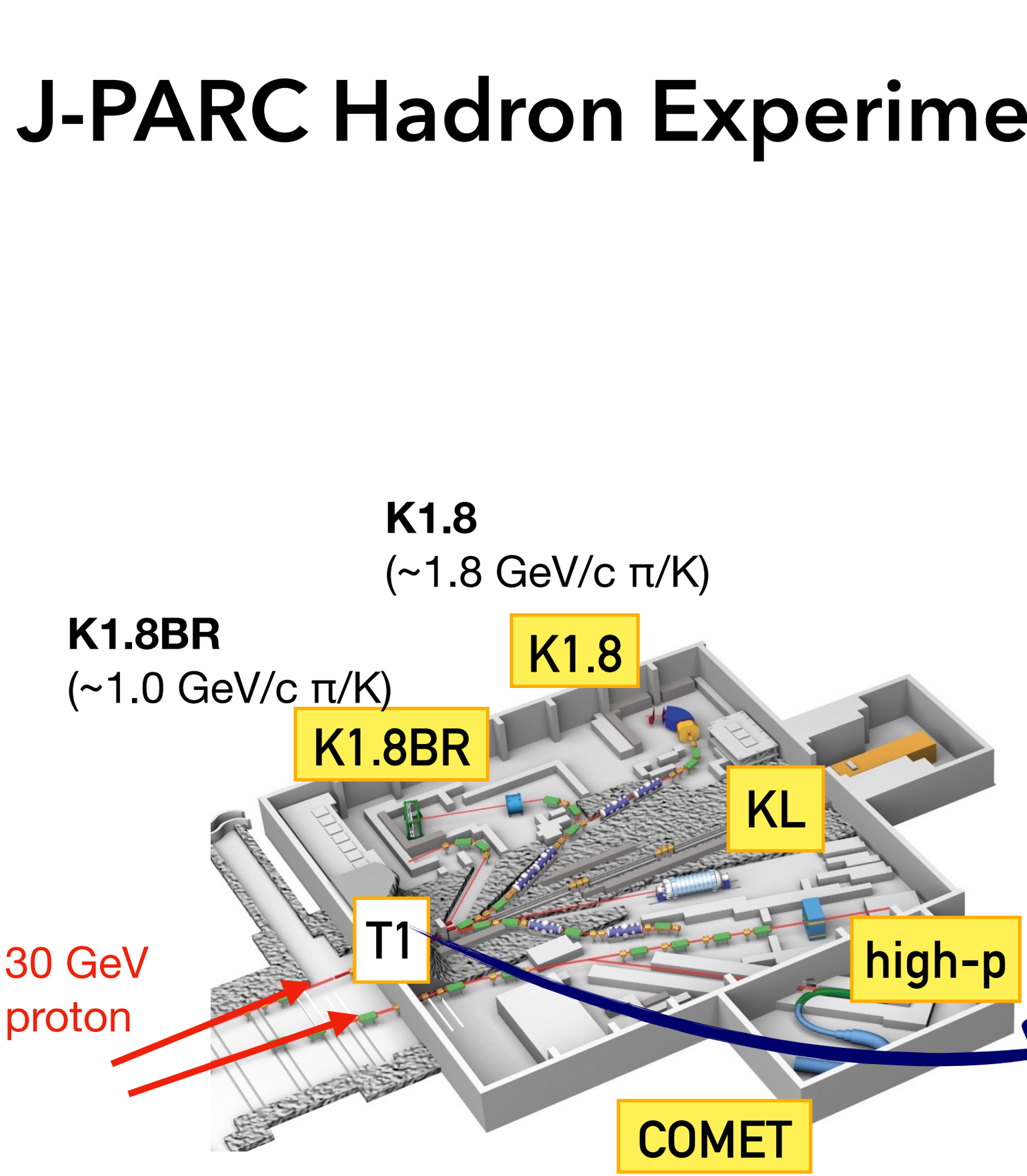


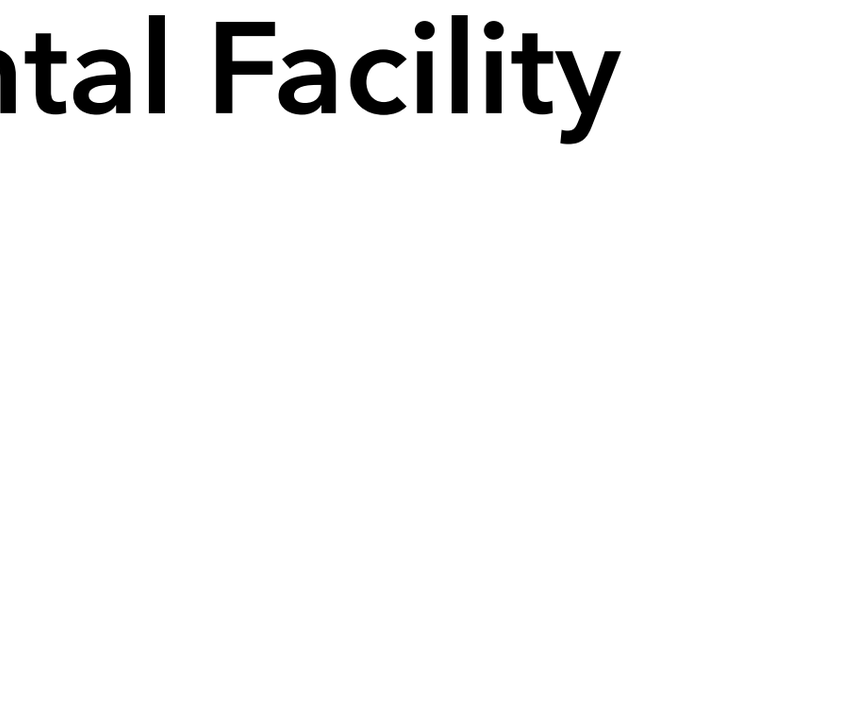


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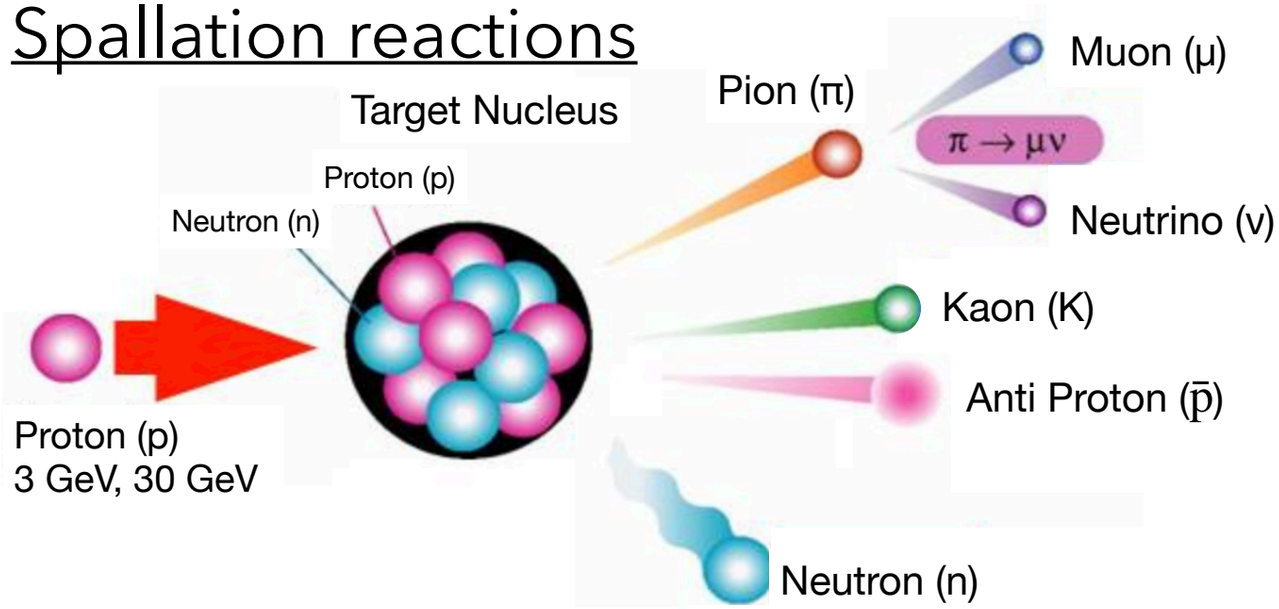
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(~1.0 GeV/c π/K)





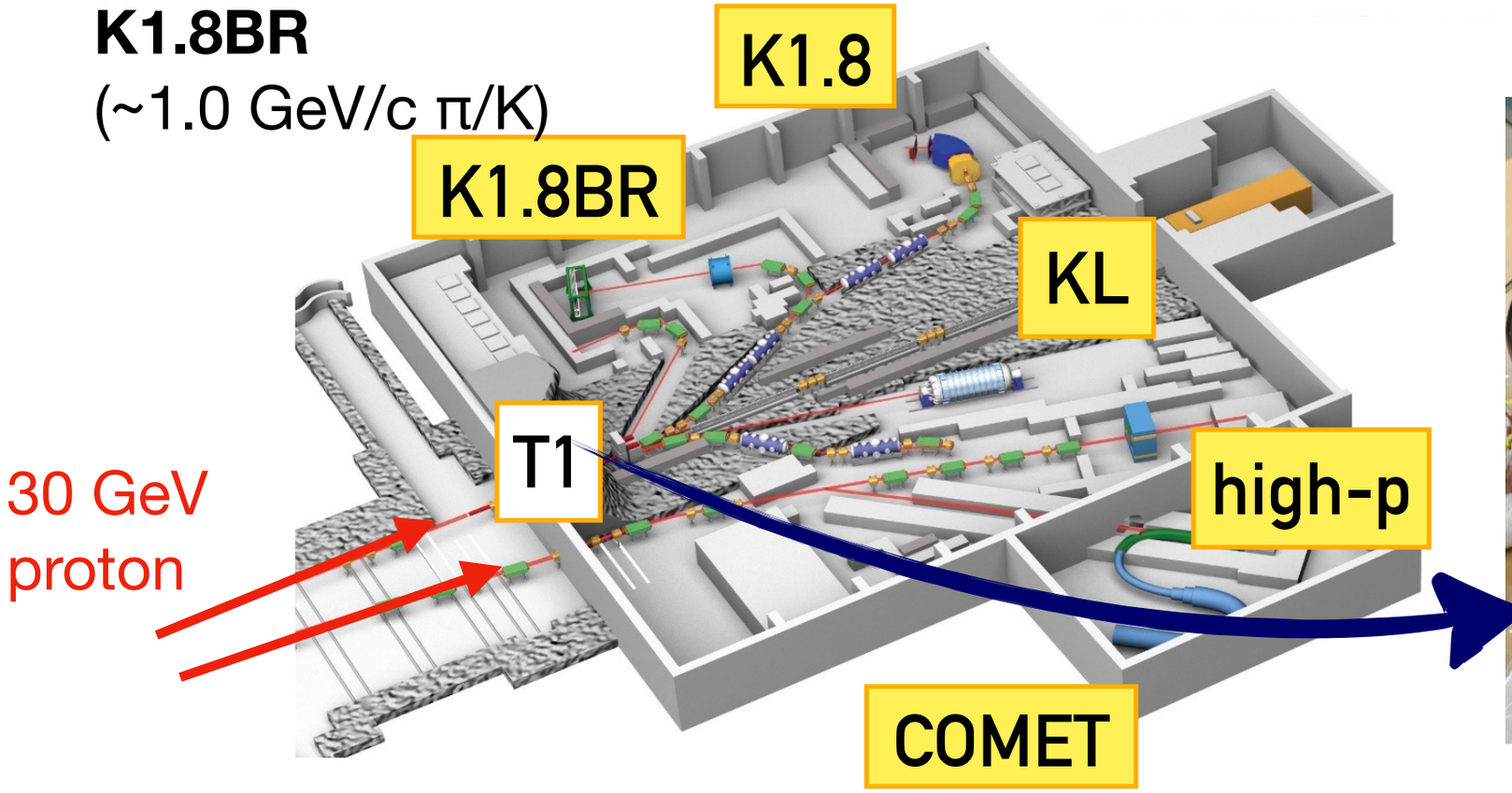
T1 Gold Target

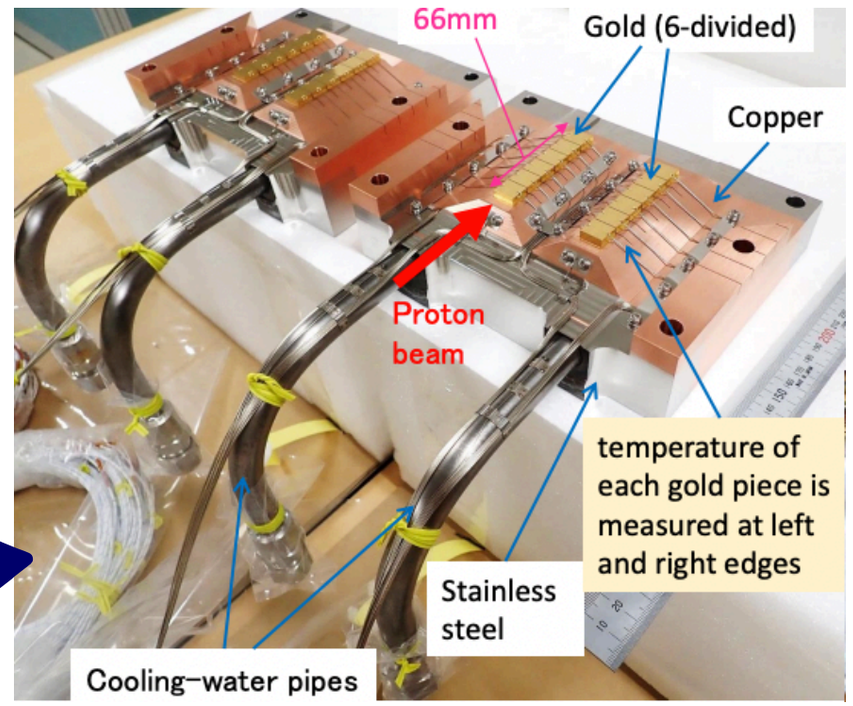
J-PARC Hadron Experimental Facility



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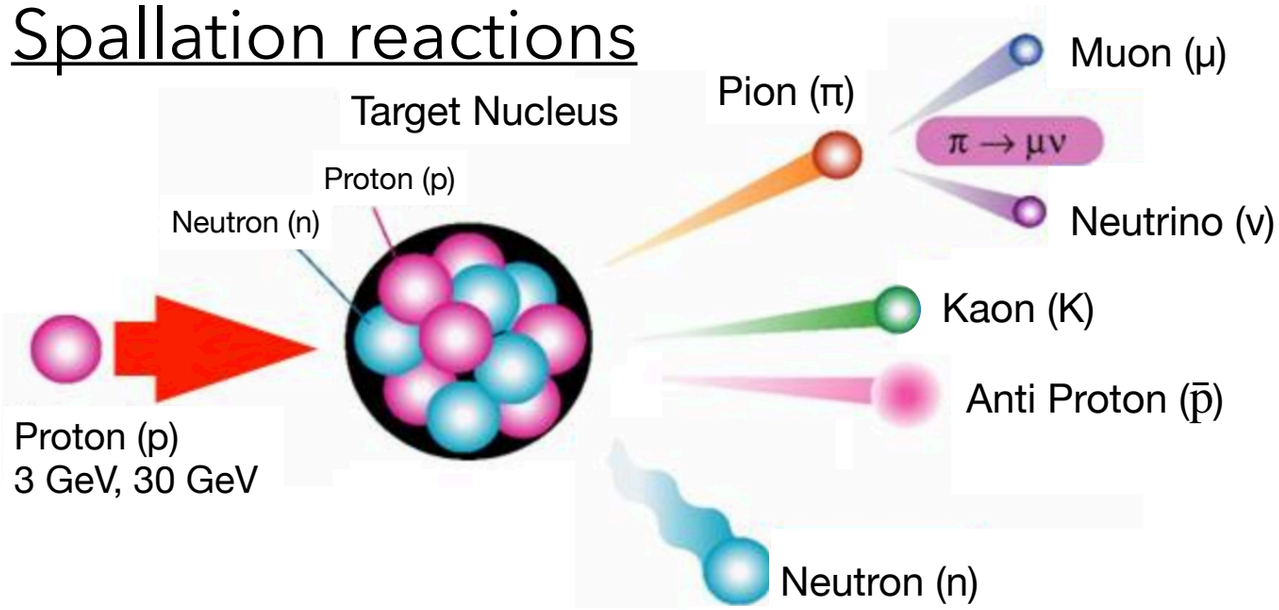
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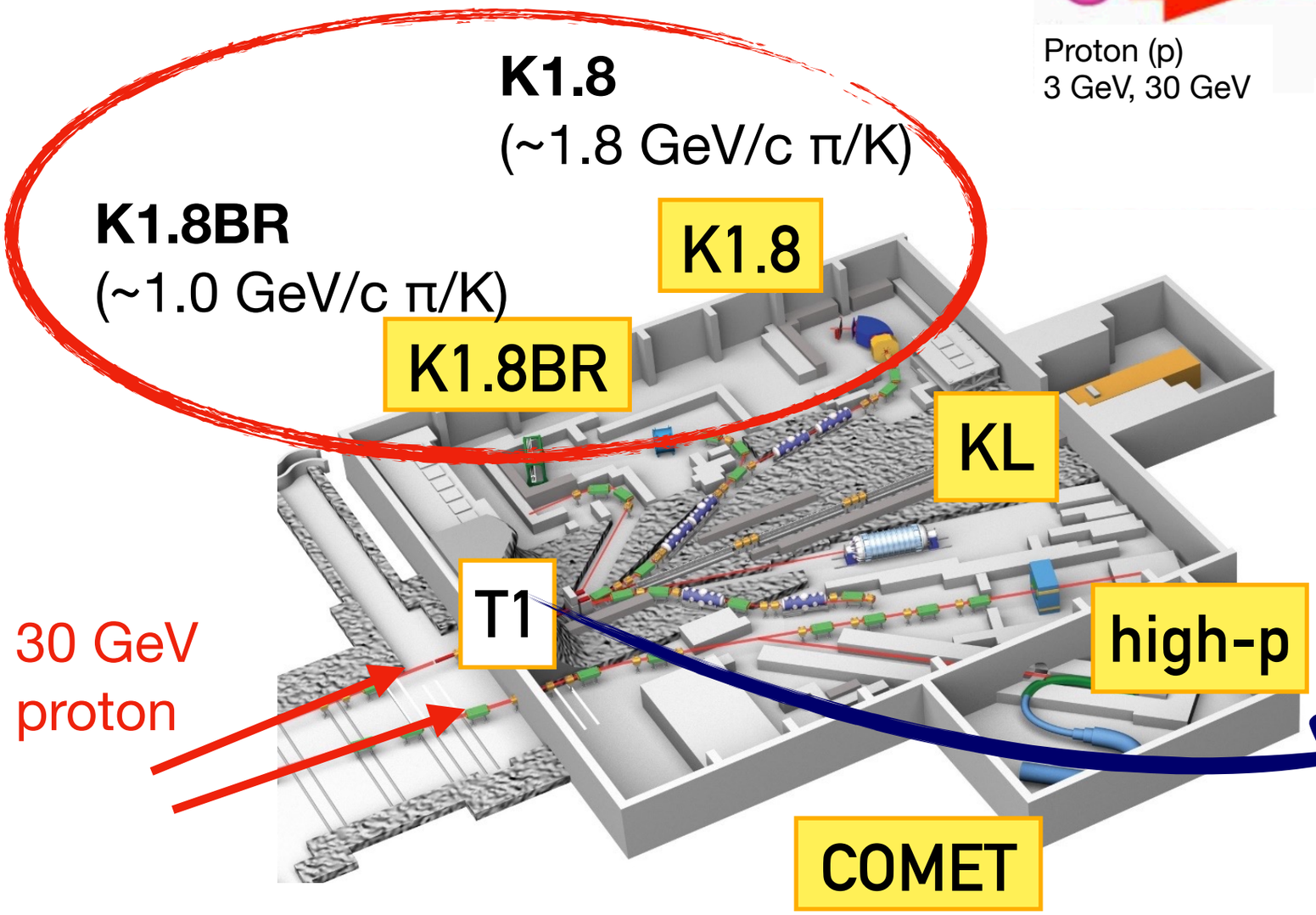


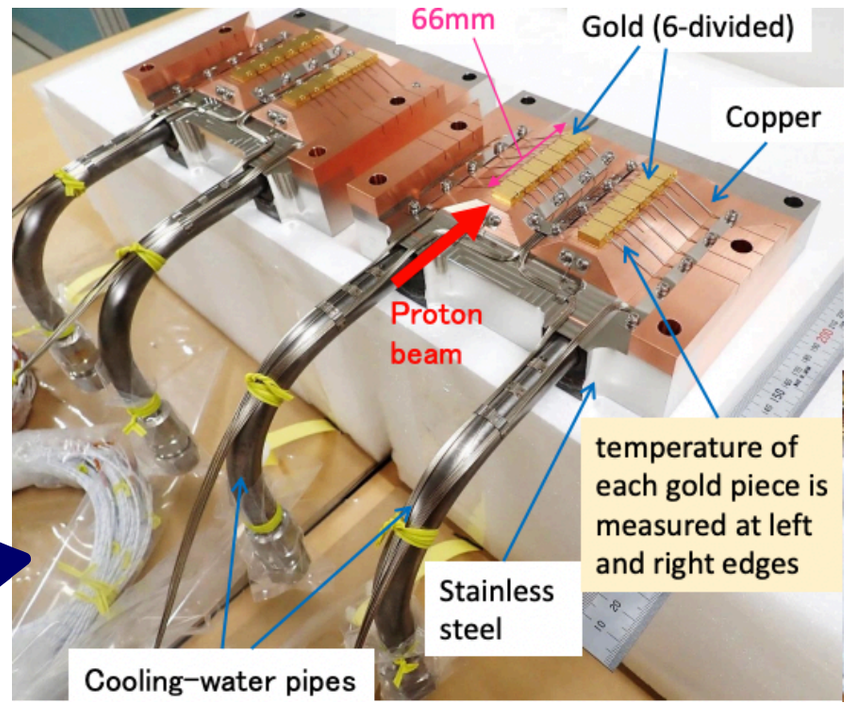


T1 Gold Target

J-PARC Hadron Experimental Facility

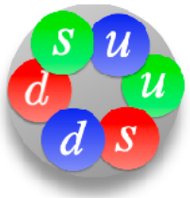






T1 Gold Target

Shared HypTPC Program



E42 *H*-dibaryon search in $^{12}C(K^-,K^+)$ reaction



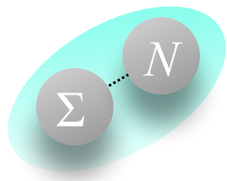
E45 N* spectroscopy in $\pi^{\pm}p \to \pi\pi N$ reaction



E72 New Λ* search in $p(K^-,\Lambda)\eta$ reaction



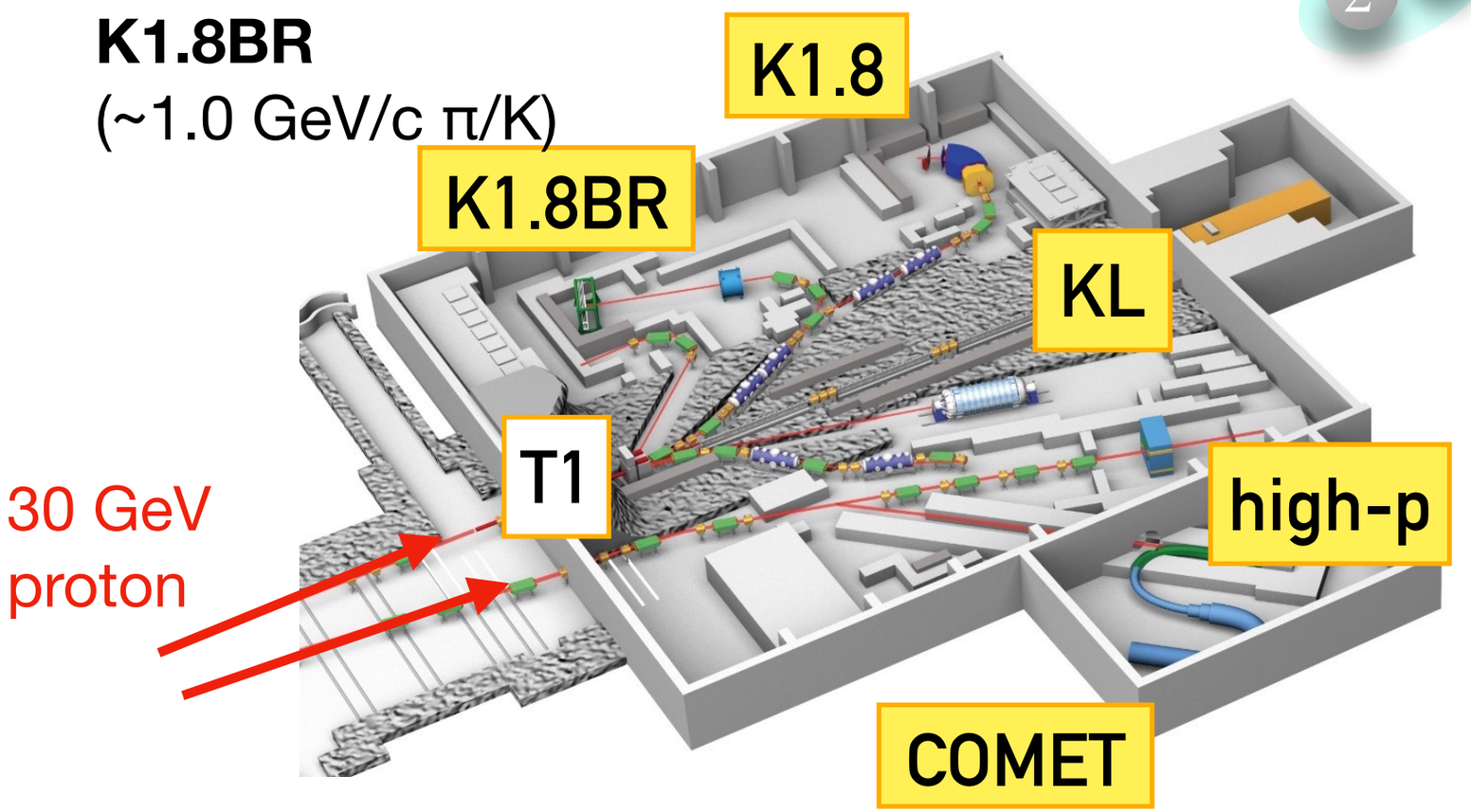
E104 $\bar{p}p \to \phi\phi$ reaction



E90 ΣN cusp study in $d(K^-,\pi^-)\Lambda p$ reaction

K1.8
(~1.8 GeV/c π/K)

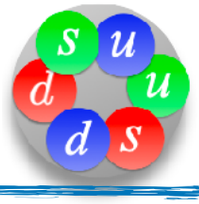
K1.8BR
(~1.0 GeV/c π/K)



J-PARC HypTPC Collaboration

Shared HypTPC Program

Upcoming shared campaign at K1.8BR



E42 *H*-dibaryon search in $^{12}C(K^-,K^+)$ reaction



E72 New Λ* search in $p(K^-,\Lambda)\eta$ reaction

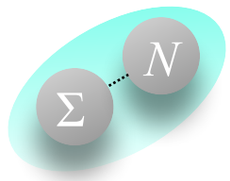


E45 N* spectroscopy in $\pi^{\pm}p \to \pi\pi N$ reaction



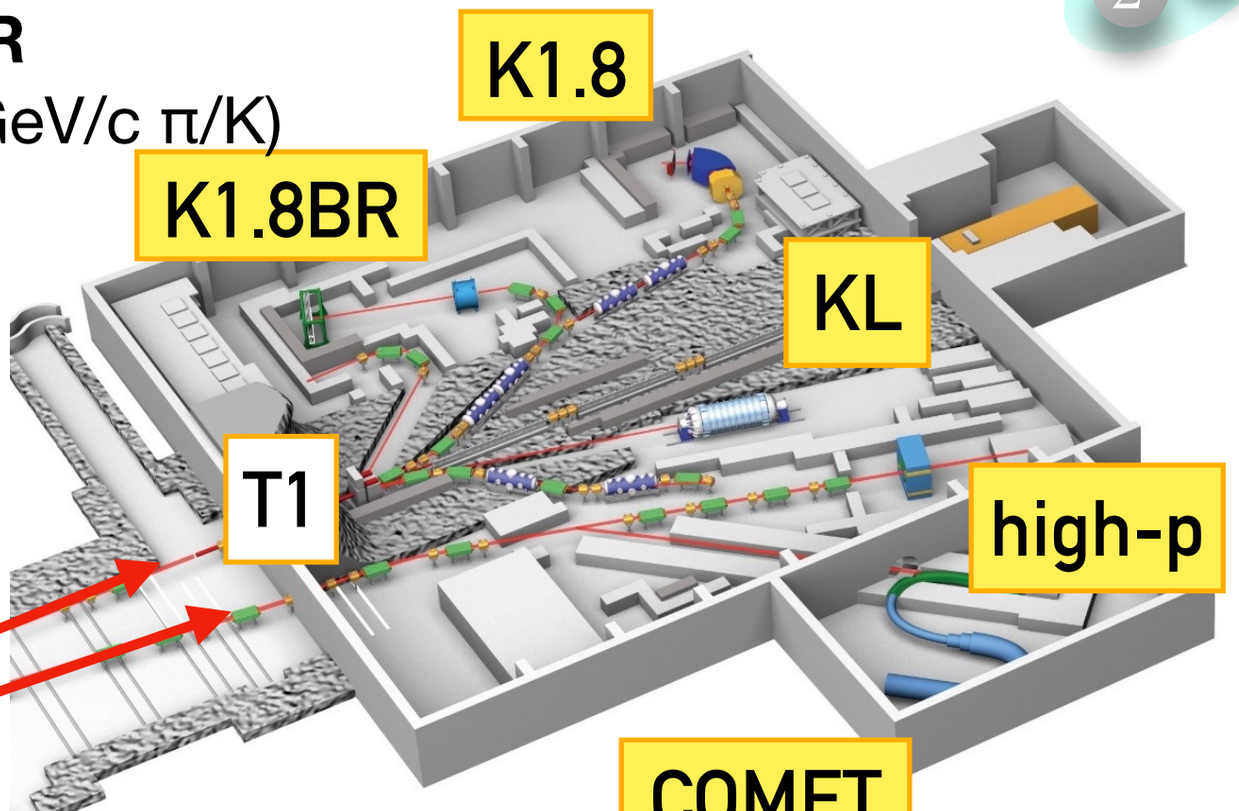
E104 $\bar{p}p \to \phi\phi$ reaction

K1.8
(~1.8 GeV/c π/K)



E90 ΣN cusp study in $d(K^-,\pi^-)\Lambda p$ reaction

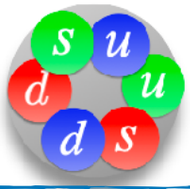
K1.8BR
(~1.0 GeV/c π/K)



J-PARC HypTPC Collaboration

Shared HypTPC Program

Upcoming shared campaign at K1.8BR



E42 *H*-dibaryon search in $^{12}C(K^-,K^+)$ reaction



E72 New Λ* search in $p(K^-,\Lambda)\eta$ reaction

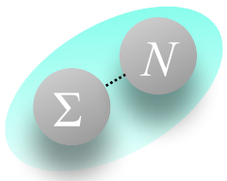


E45 N* spectroscopy in $\pi^{\pm}p \to \pi\pi N$ reaction



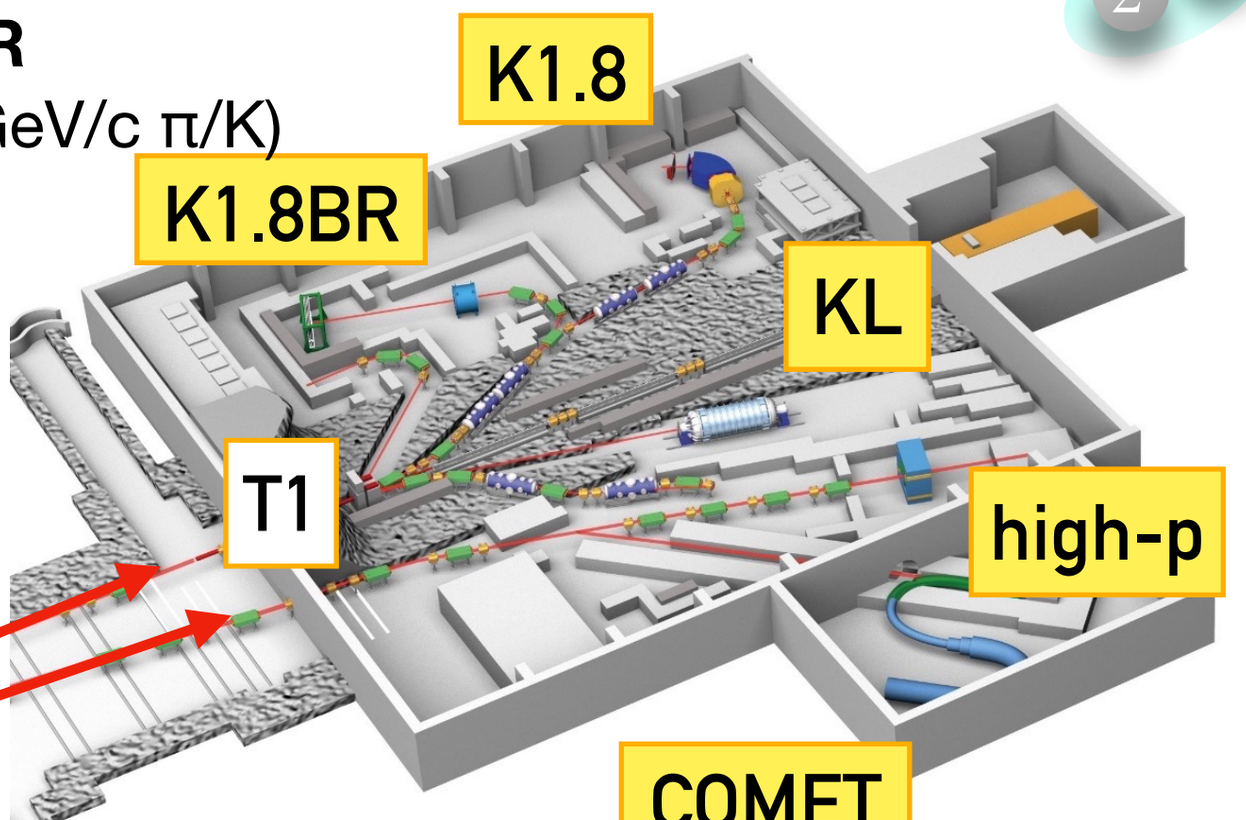
E104 $\bar{p}p \to \phi\phi$ reaction

K1.8
(~1.8 GeV/c π/K)



E90 ΣN cusp study in $d(K^-,\pi^-)\Lambda p$ reaction

K1.8BR
(~1.0 GeV/c π/K)



J-PARC HypTPC Collaboration

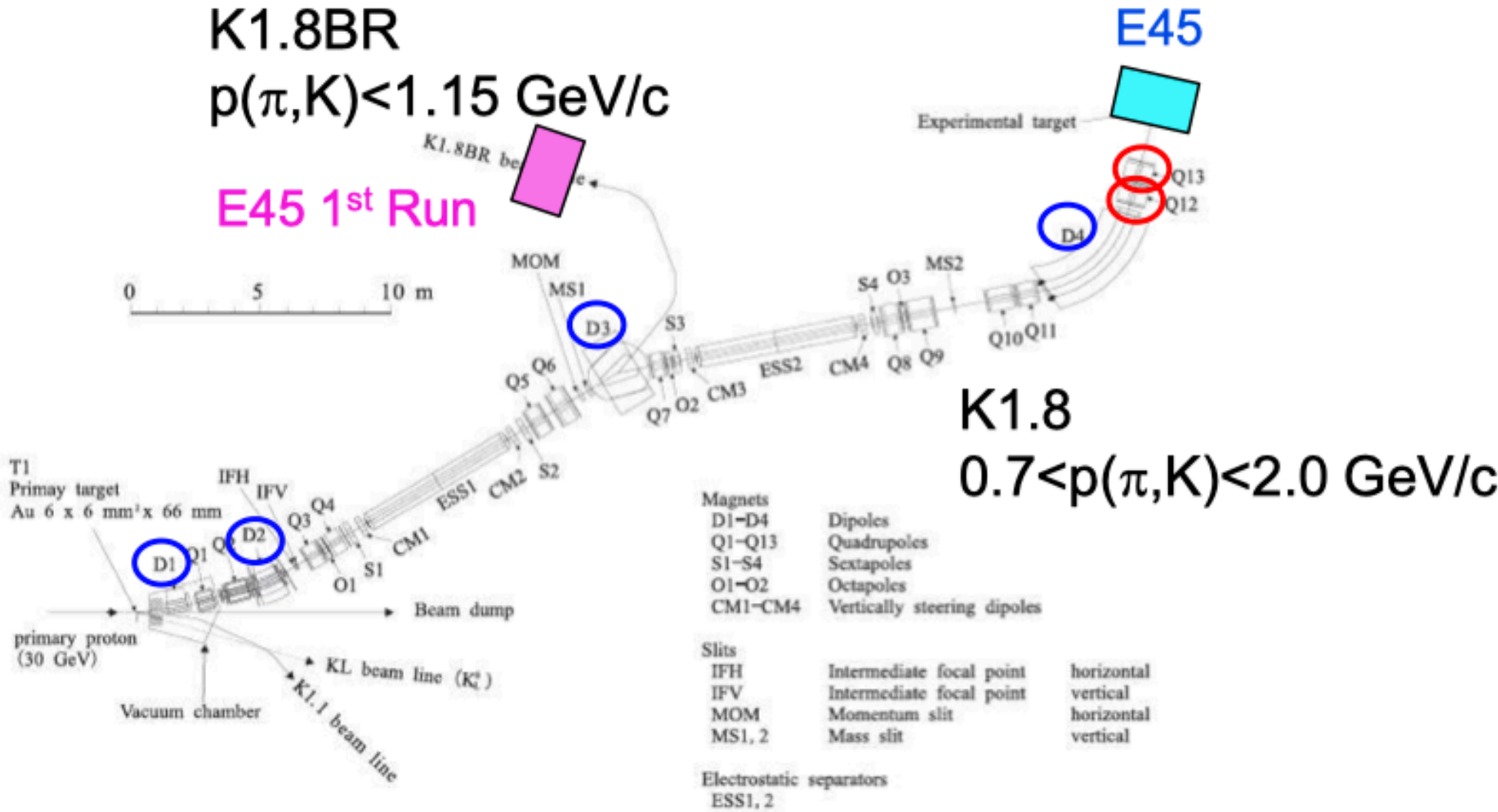
E45 at the K1.8BR and K1.8 Beamlines

- K1.8BR: **first E45 physics run**
  p_π = 0.964–1.144 GeV/c
  W ≈ 1.65–1.75 GeV
- K1.8: **full E45 energy range**
  p_π ≈ 0.73–2.0 GeV/c
  W ≈ 1.5–2.15 GeV

Shared K1.8BR campaign

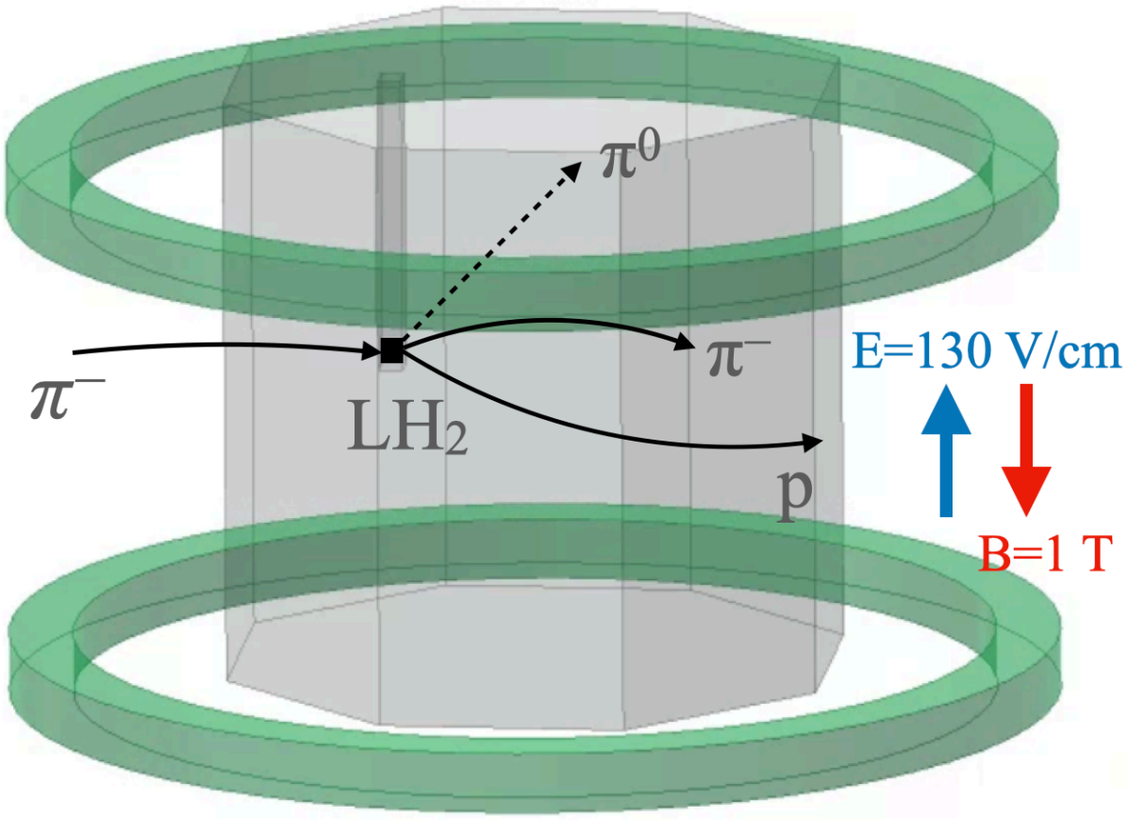
Experiment	Beam
E72	K^-
E45	$\pi^\pm$
E104	$\bar{p}$

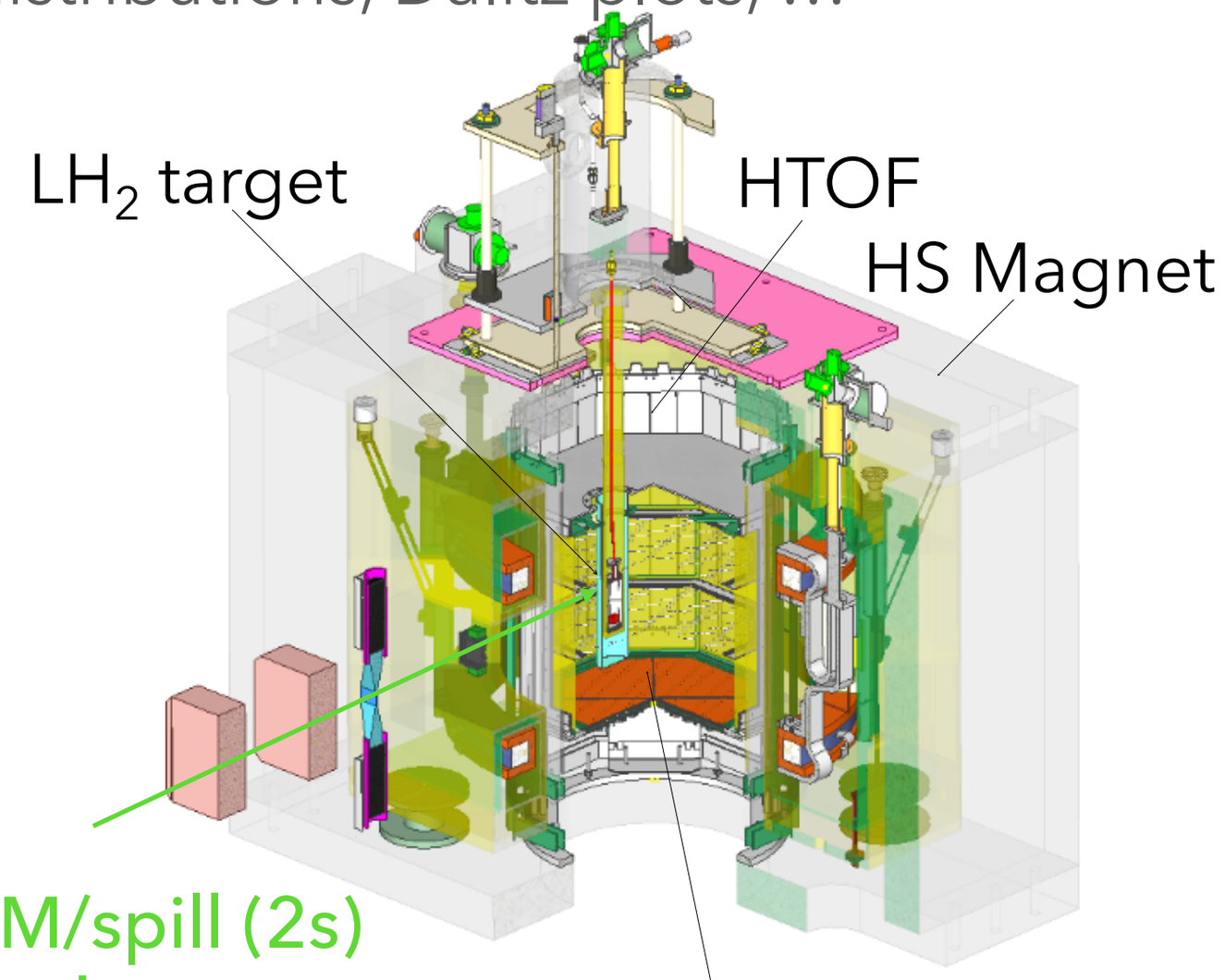
Shared commissioning and calibration
Beam species changed between runs



J-PARC E45 Experimental Setup

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

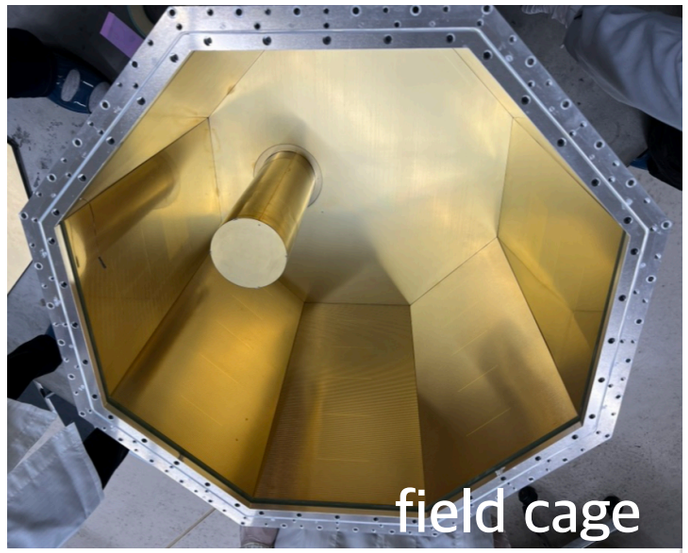


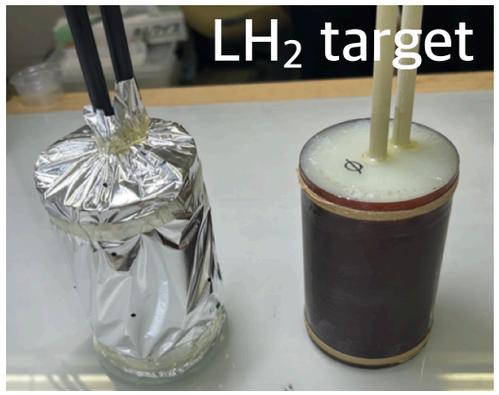


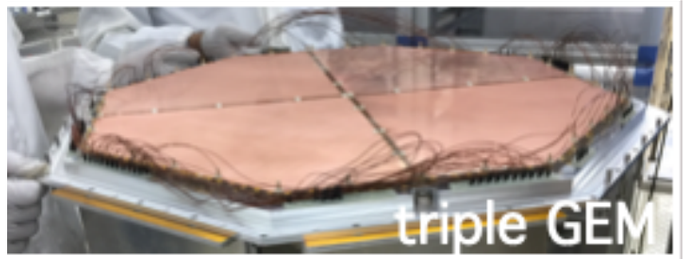
- Large acceptance (~4π)
- High rate capability (~10^6 cps)

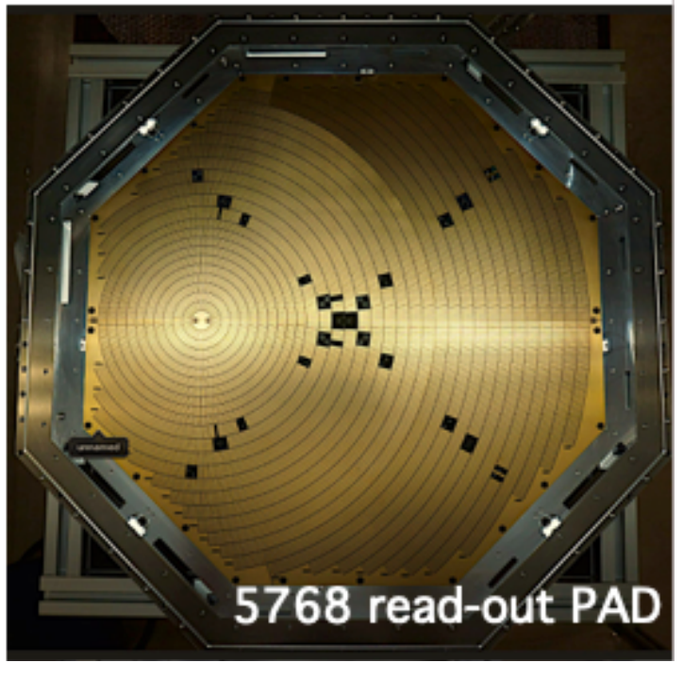
- *Hyperon Spectrometer*

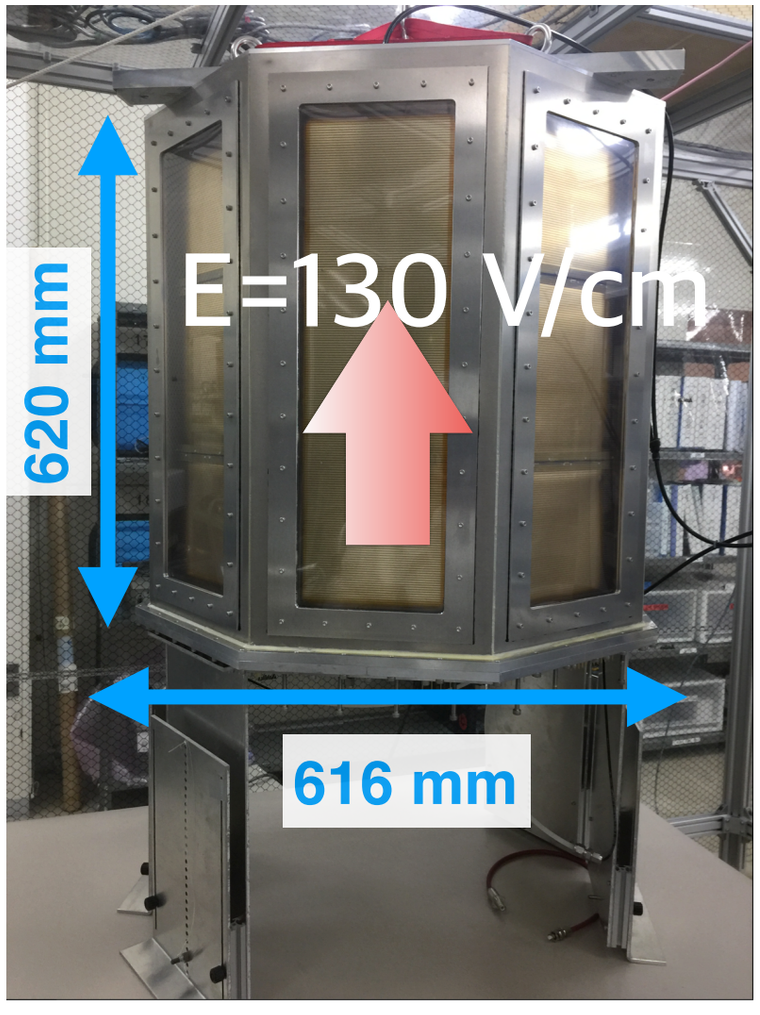
Hyperon Spectrometer

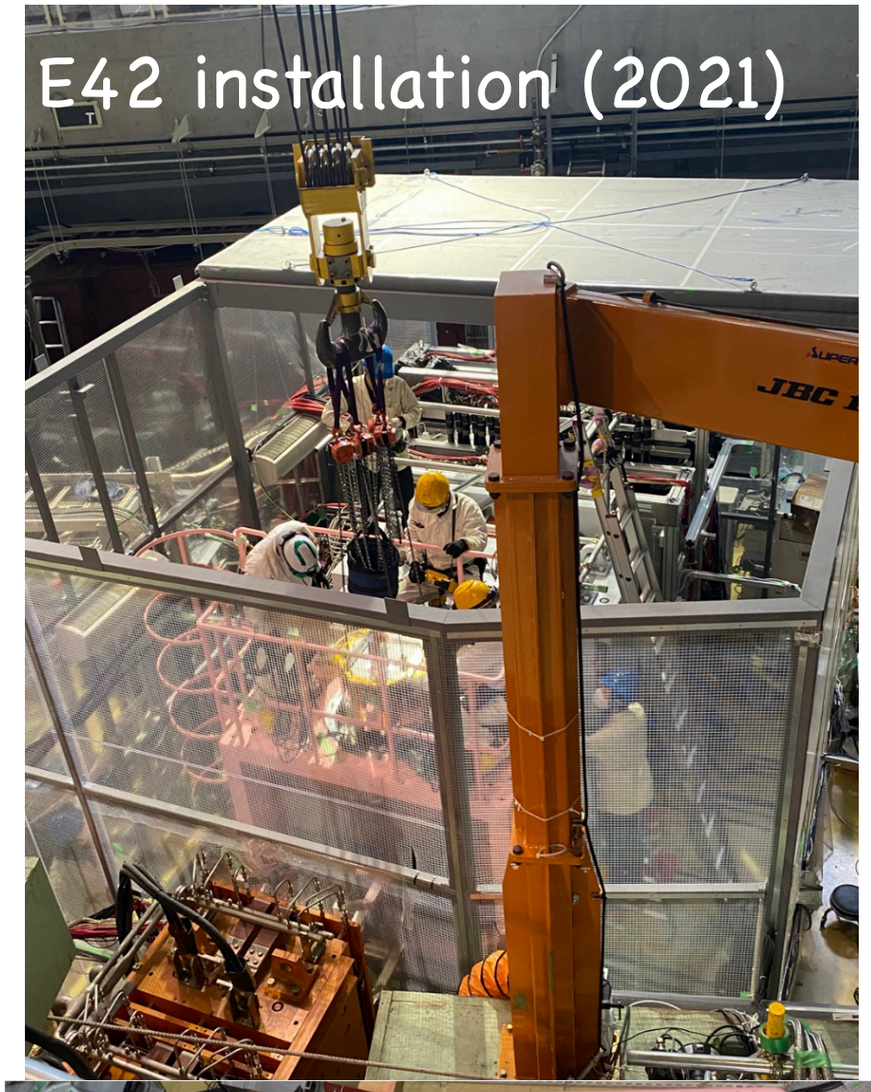


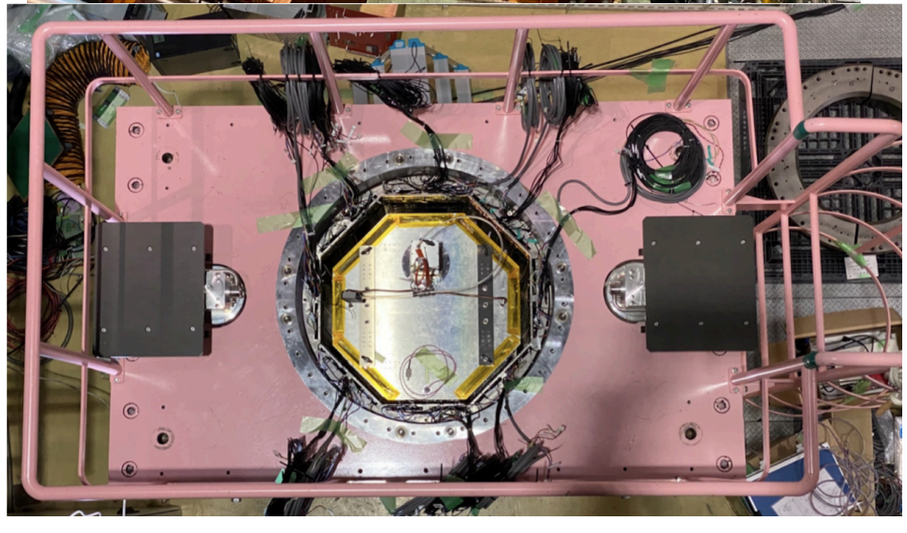












- *HypTPC*

Reaction Channels and HTOF Trigger

- Physics-trigger concept: HTOF multiplicity ≥ 2 for final states with charged particles

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

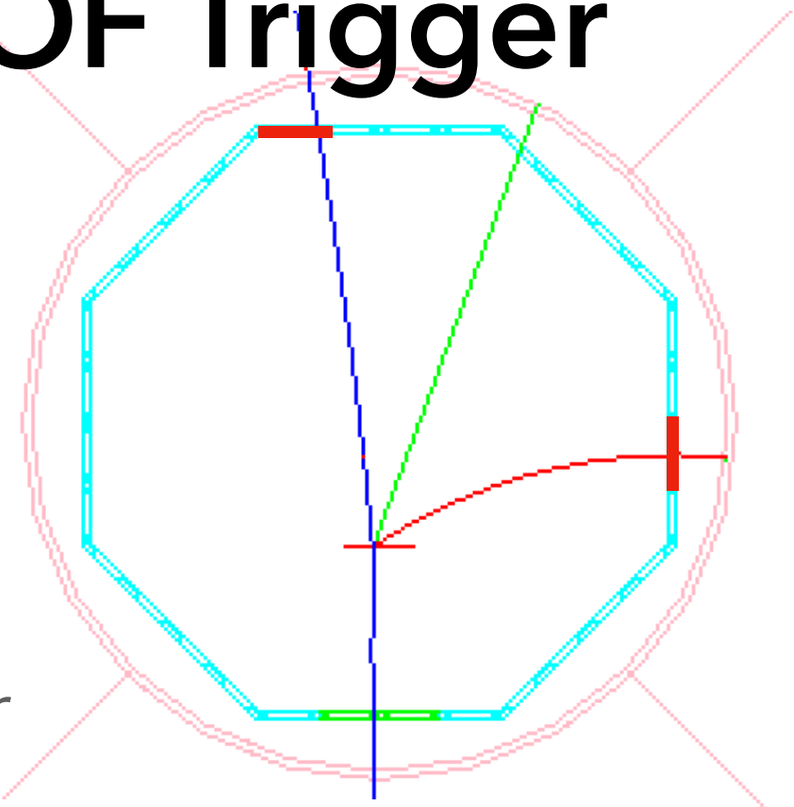
$\pi^- p \rightarrow \pi^+\pi^- n$, $\pi^0\pi^- p$,
$\pi^+ p \rightarrow \pi^0\pi^+ p$, $\pi^+\pi^+ n$

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

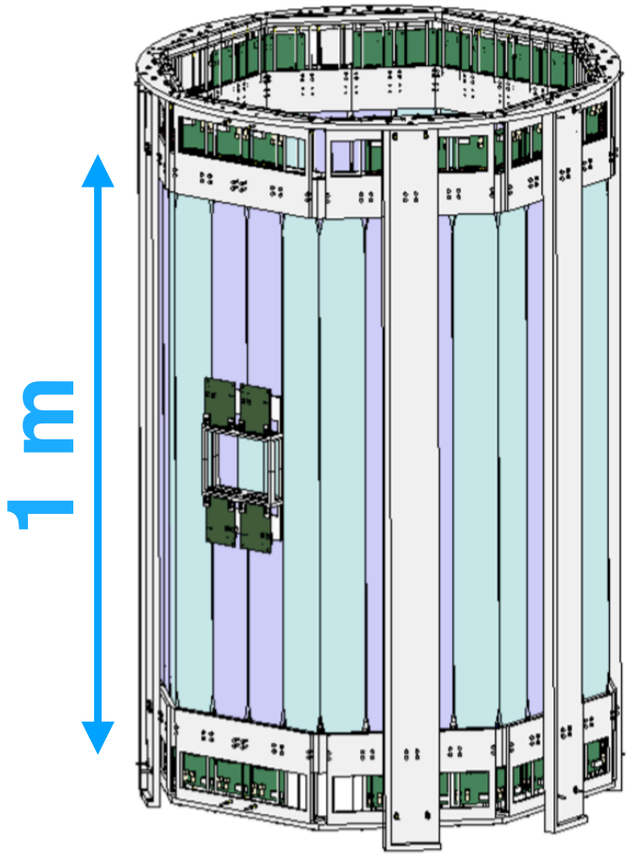
$\pi^- p \rightarrow \pi^- p$,
$\pi^+ p \rightarrow \pi^+ p$

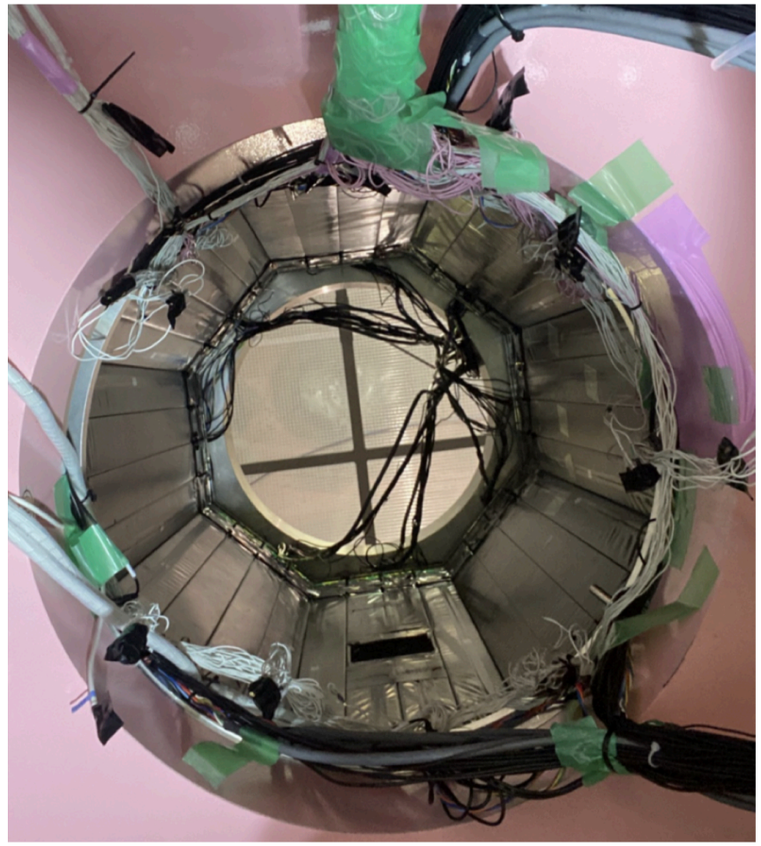
- $\pi p \rightarrow KY$ reactions

$\pi^\pm p \rightarrow K\Lambda$, $K\Sigma$



- *HTOF detector*

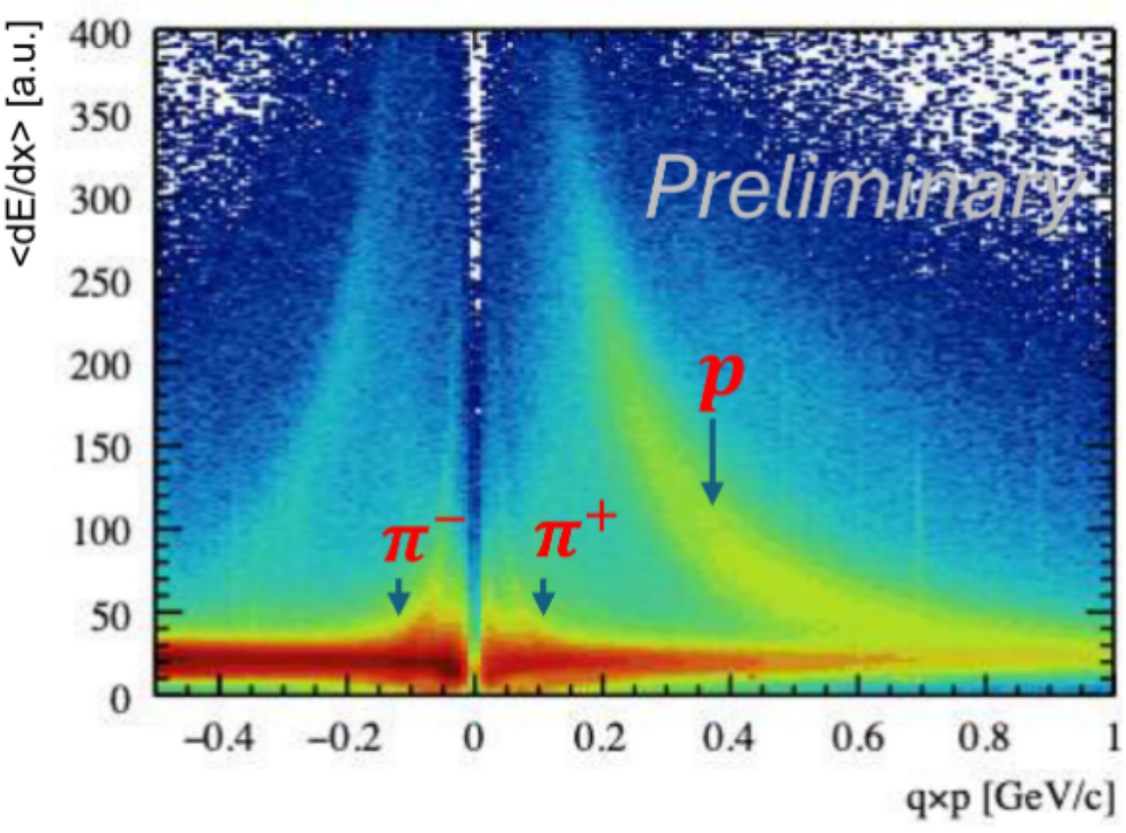




Commissioning and Trigger Studies

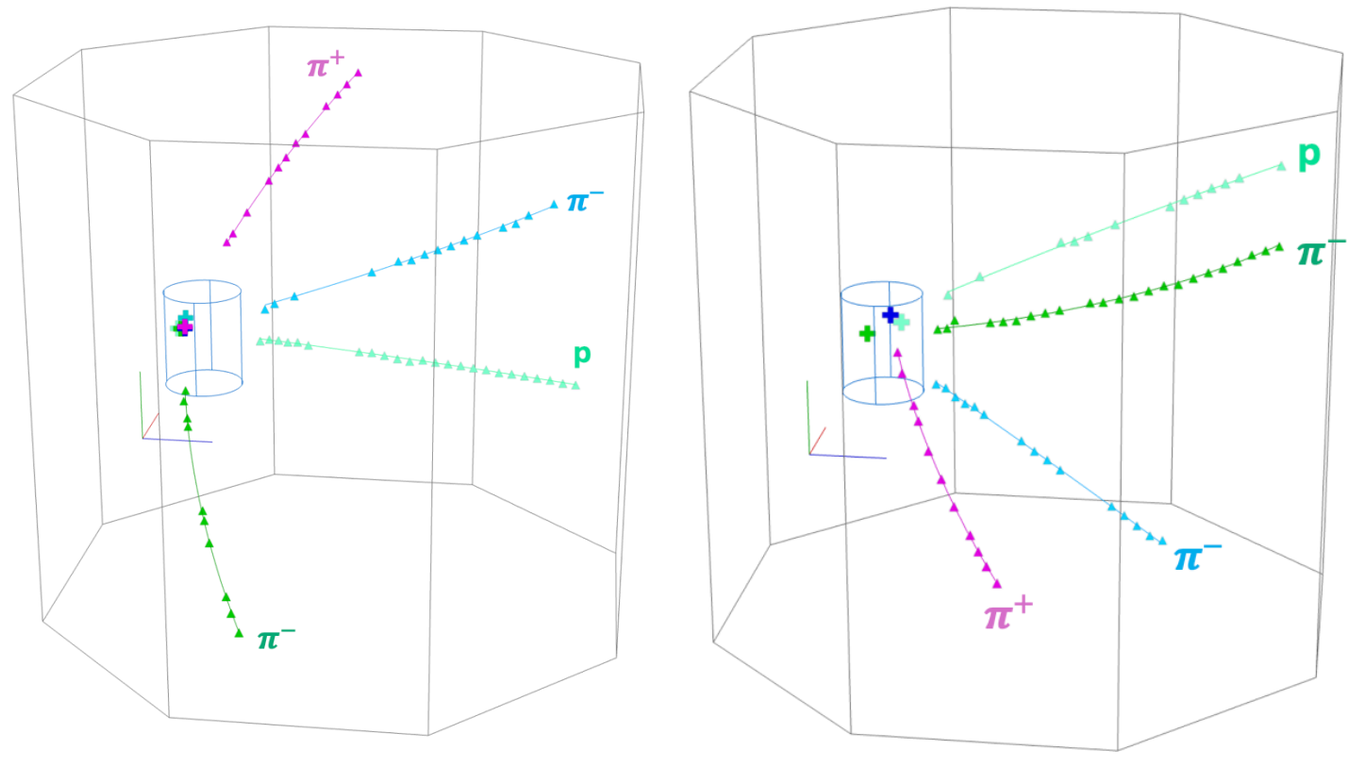
- Trigger studies achieved ≈3k triggers/spill at ≈300k π^-/spill.
  - HTOF-Mp2 with beam-background suppression
- Example dataset: π^- at 1.0 GeV/c, HTOF-Mp3, ≈6M triggered events

TPC dE/dx particle identification



$\pi^- p \to K^0 \Lambda$ event candidates

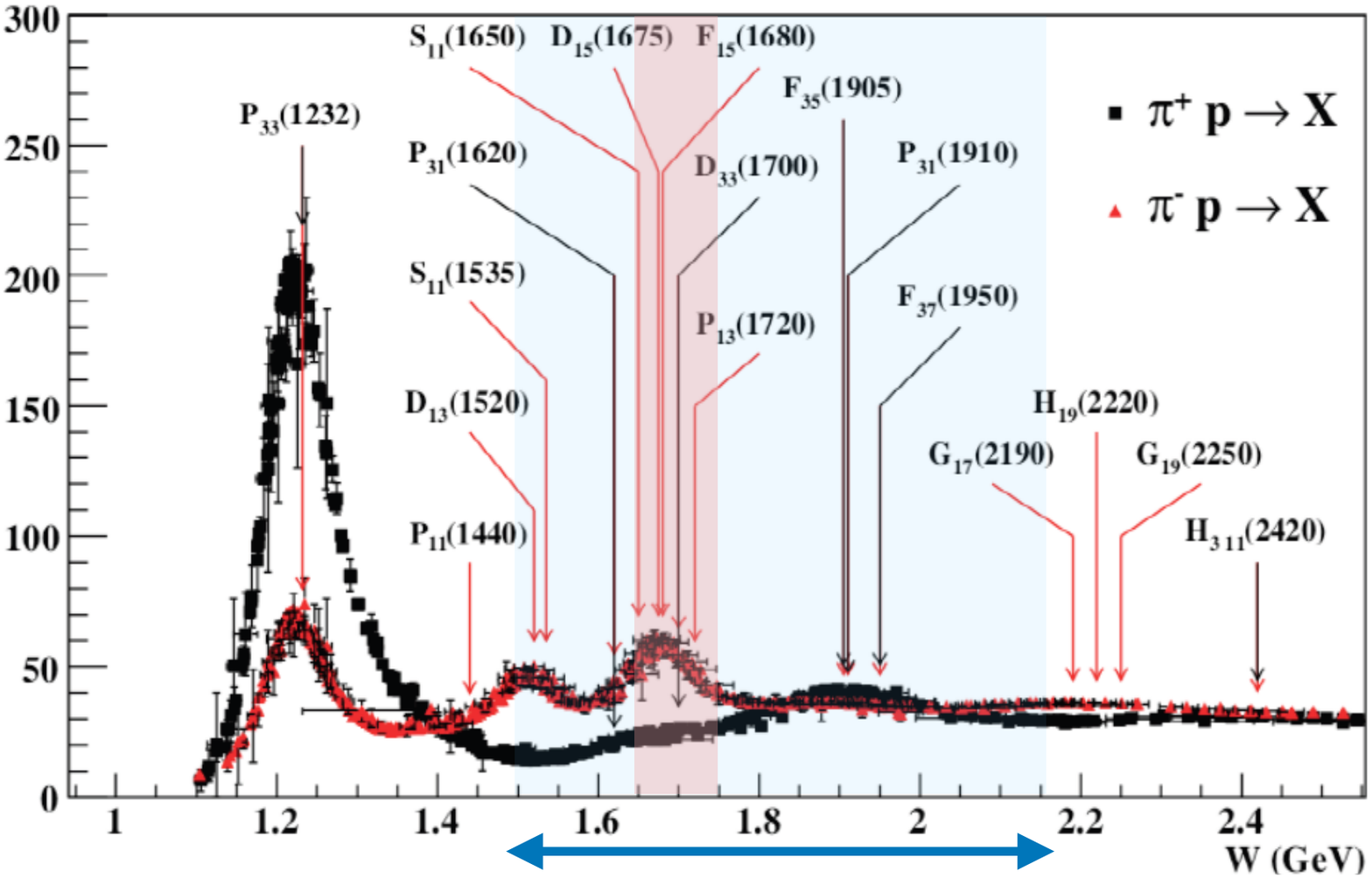
$(K^0_S \to \pi^+\pi^-; \Lambda \to p\pi^-)$



Preliminary: particle identification and multitrack reconstruction

First Physics Run: W=1.65-1.75 GeV

Existing π±p total cross sections



Full E45 program: W = 1.5–2.15 GeV

Third resonance region (1.65–1.75 GeV)

Five nominal settings with both π^- and π^+ beams

p_π (GeV/c)	W (GeV)
0.964	1.652
1.025	1.686
1.055	1.702
1.114	1.734
1.144	1.750

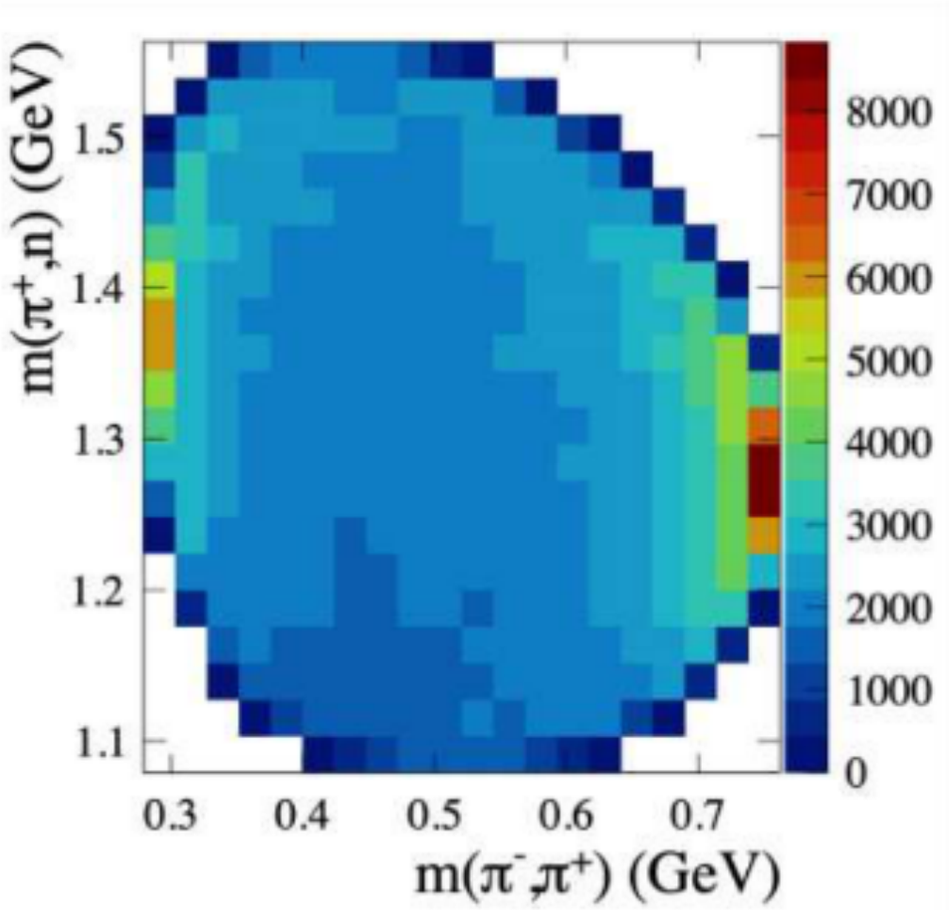
Measure the energy dependence and differential distributions of ππN production

Acceptance for Exclusive Reactions

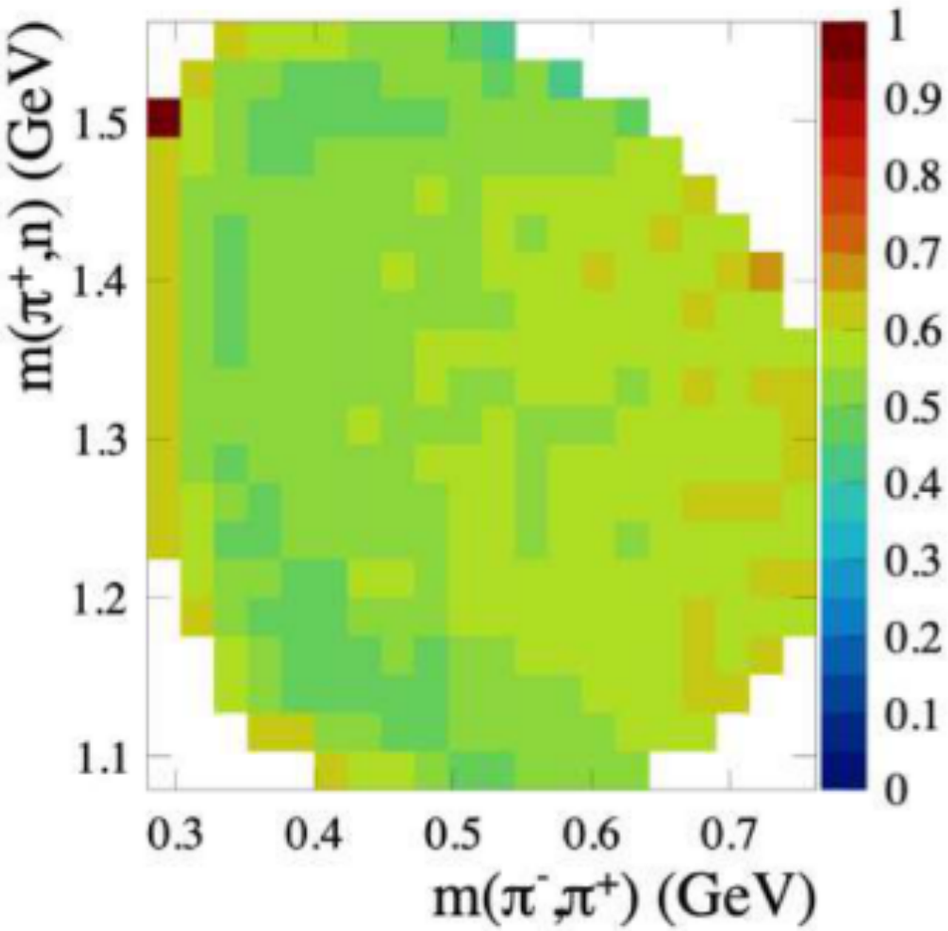
- Acceptance varies across the final-state phase space.
- The simulation evaluates acceptance in 20 × 20 Dalitz bins.

$\pi^- p \rightarrow \pi^- \pi^+ n$ · Phase-space simulation

Simulated event distribution



Acceptance in each bin



Bin-by-bin acceptance corrections are essential for extracting differential cross sections.

Beam-Time Allocation and Yields

60 h total: 56.6 h physics + 3.4 h estimated for momentum and charge changes

p_π (GeV/c)	W (GeV)	π^- time (h)	π^+ time (h)	$\pi^- \rightarrow \pi\pi N$ (M events)	$\pi^+ \rightarrow \pi\pi N$ (M events)
0.964	1.652	2.31	7.64	1.689	3.818
1.025	1.686	2.24	7.85	1.635	3.809
1.055	1.702	2.28	9.07	1.603	4.086
1.114	1.734	2.39	10.73	1.543	4.461
1.144	1.750	2.68	9.43	1.533	3.954
Total		**11.89**	**44.71**	**8.003**	**20.128**

≈ 0.606M per setting in the lower cross-section channel for each beam charge

$\pi^- p \rightarrow \pi^0 \pi^- p$ and $\pi^+ p \rightarrow \pi^+ \pi^+ n$

Four ππN channels: ≈ 28.1M planned events in total

50% acceptance assumed; trigger, DAQ live time and reconstruction efficiencies not included.

Summary

➔ The J-PARC E45 will provide a unique opportunity to study *N** and *Δ** resonances through exclusive **$\pi^{\pm}p \rightarrow \pi\pi N$ and *KY*** measurements over the wide energy range of **W=1.5 - 2.15 GeV.**

➔ Commissioning data demonstrate particle identification and multi-track reconstruction.

➔ The first physics run will focus on the third resonance region (W = 1.65–1.75 GeV), using both pion charges.

We are now preparing for the first physics run.
The shared campaign is expected to begin in late November.

Thank you for your attention