Studies of N* and Δ* in πN →ππN reactions at J-PARC

Hiroyuki Sako (ASRC/J-PARC, JAEA)
for the J-PARC E45 Collaboration

NSTAR 2026, Sevilla
7-11 Sep. 2026

1. Introduction
2. Run plan in Nov.-Dec. 2026
3. Preparation status
4. Summary and Prospect

E45 Collaboration

Co-spokespersons: H. Sako (JAEA), P. L. Cole (Lamar U), S.H. Kim (Kyungpook National U)

- S. Hasegawa, K. Hosomi, K. Imai, S. Sato, K. Tanida, T. Yamamoto (JAEA)
- Y. Ichikawa, S. Hayakawa, F. Oura, R.J. Saito, K. Amemiya, K. Shimazaki, R. Sasaki, Y. Nakayama, T. Nanamura, J. Yoshida (Tohoku U)
- C. Djalali (Ohio U)
- J.K. Ahn, S. Yang, W.S. Jung, B.M. Kang, S.W. Choi, H.I. Lee, J.R. Kumar, D.H. Choi, S.H. Kang (Korea U)
- A. Higashi, T. Ishikawa, H. Kamano, K. Mizutani, T. Sato, K. Shirotori, T.N. Takahashi (RCNP, Osaka U)
- S.H. Hwang (KRISS)
- M. Naruki, N. Tomida (Kyoto U)
- K. Ozawa, H. Sugimura, T. Takahashi, M. Ukai (KEK)
- K. Joo, A. Kim, Y. Wunderlich (U Connecticut)
- W.J. Briscoe, I. Strakovsky**, R. Workman** (George Washington U)
- L. Guo (Florida International U)
- T.S.-H. Lee (ANL)
- **A. Sarantsev** (U Bonn)
- Y. Han (INEST)
- S. X. Nakamura (Shandong U)
- M. Niiyama (Kyoto Sangyo U)
- J. J. Lee, H. J. Byeon (Kyungpook National U)
- T. Chetry (Mississippi State U)
- T. Hashimoto, K. Nakazawa (RIKEN)
- H. S. Lee (IBS)
- H. Fujioka (Institute of Science Tokyo)

Goals of E45

Studies of baryon resonances in (π,2π) reactions for:

- Precise measurements of baryon resonance properties up to ~2 GeV/c^2
  - Many resonances have not been established experimentally
  - Short of (π,2π) experimental data since 1970's
- Deeper understanding of non-perturbative QCD
- Search for new baryon states
  - *e.g.* hybrid baryons (qqqg)

PDG2024

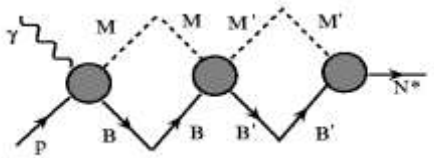
N	$1/2^+$	****	$\Delta(1232)$	$3/2^+$	****
$N(1440)$	$1/2^+$	****	$\Delta(1600)$	$3/2^+$	****
$N(1520)$	$3/2^-$	****	$\Delta(1620)$	$1/2^-$	****
$N(1535)$	$1/2^-$	****	$\Delta(1700)$	$3/2^-$	****
$N(1650)$	$1/2^-$	****	$\Delta(1750)$	$1/2^+$	*
$N(1675)$	$5/2^-$	****	$\Delta(1900)$	$1/2^-$	***
$N(1680)$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

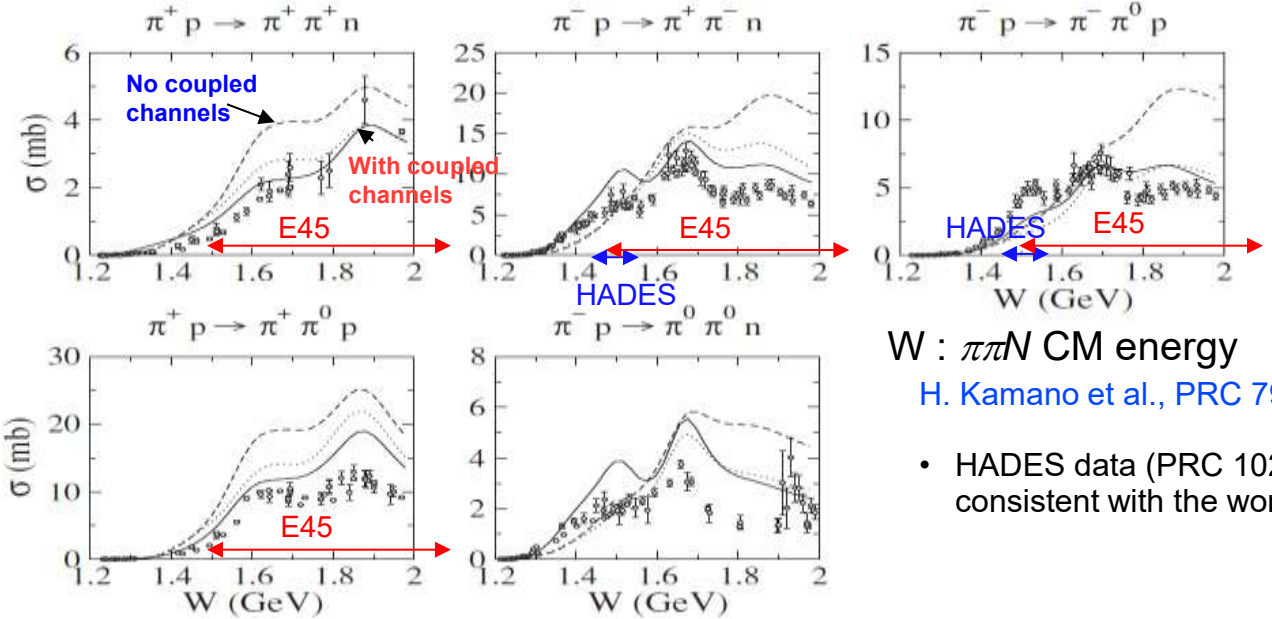
World's $\pi N \to \pi\pi N$ data

Only 240K events measured in the 1970s

Dynamical Coupled Channel model (ANL-Osaka)
Inclusion of intermediate meson-baryon channels :

$$(\gamma^{(*)}N,\ \pi N,\ \overbrace{\eta N,\ \pi\Delta,\ \sigma N,\ \rho N,}^{\pi\pi N}\ K\Lambda,\ K\Sigma,\cdots)$$





W : $\pi\pi N$ CM energy

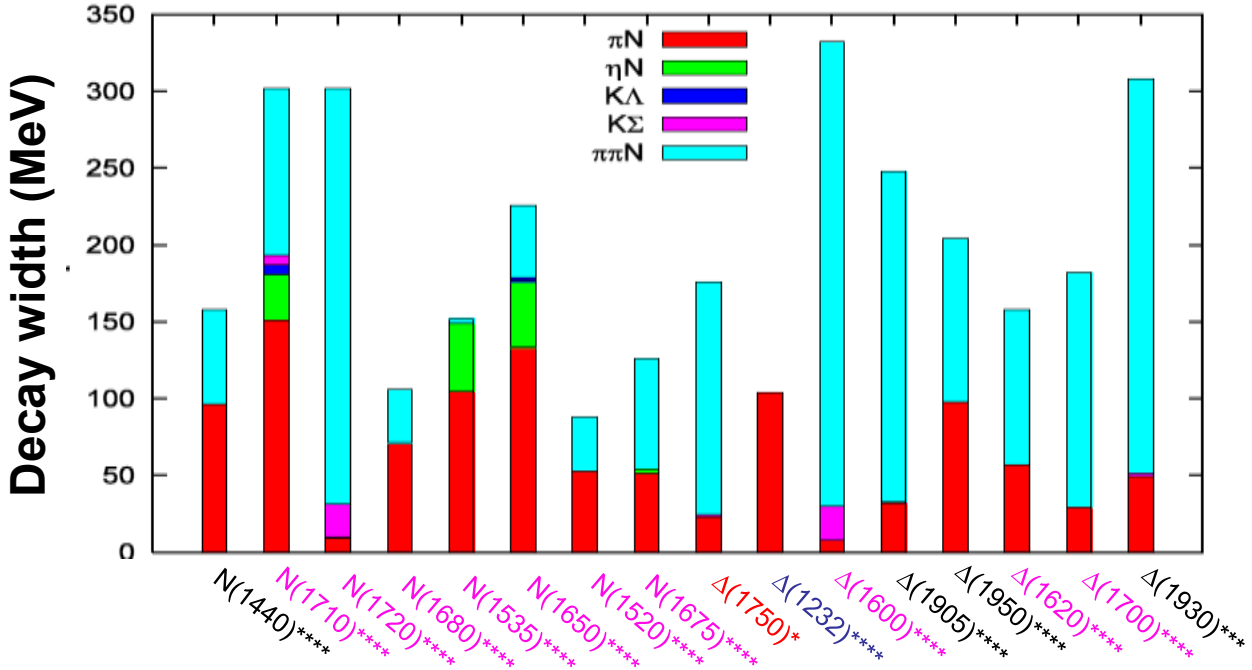
H. Kamano et al., PRC 79 025206 (2009).

- HADES data (PRC 102, 024001 (2020)) is consistent with the world's data.

Importance of $\pi\pi N$ Decay

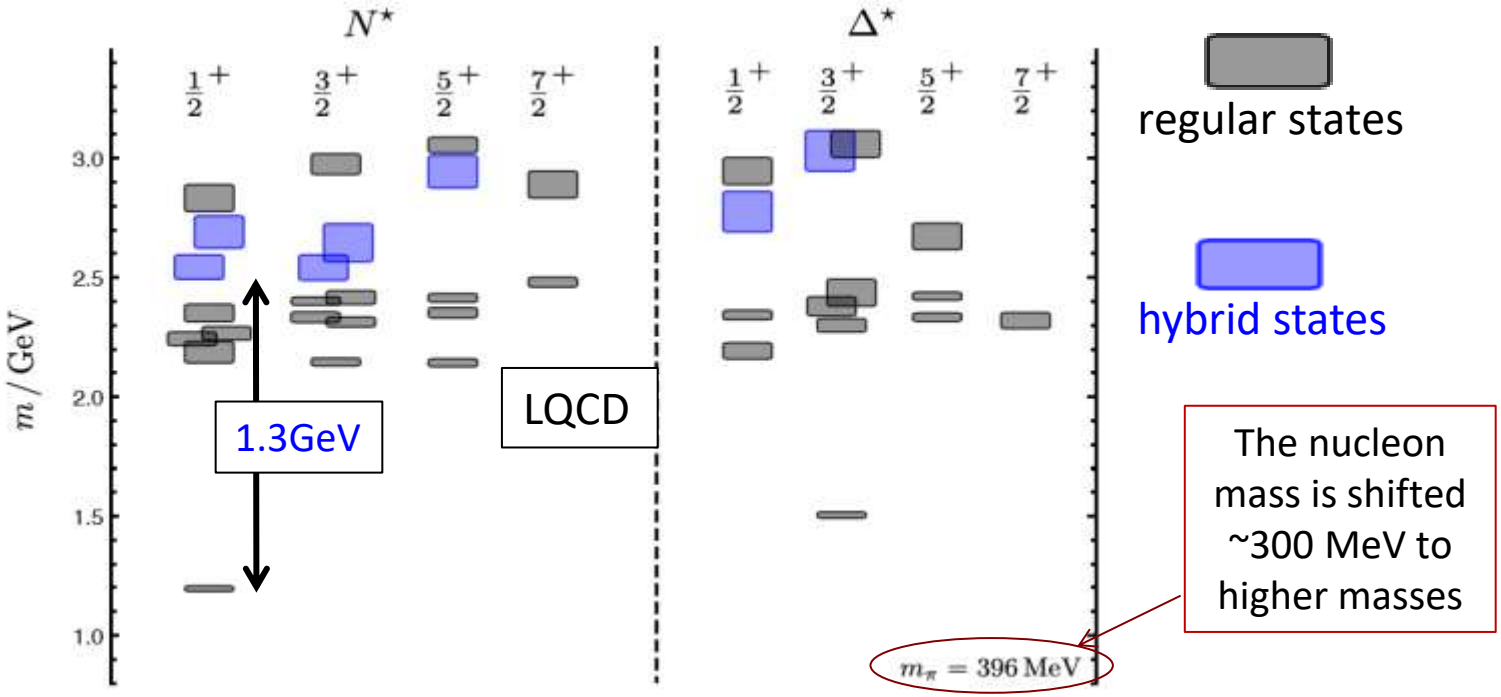
There are many N* and Δ* resonances that dominantly couple to the ππN channel

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

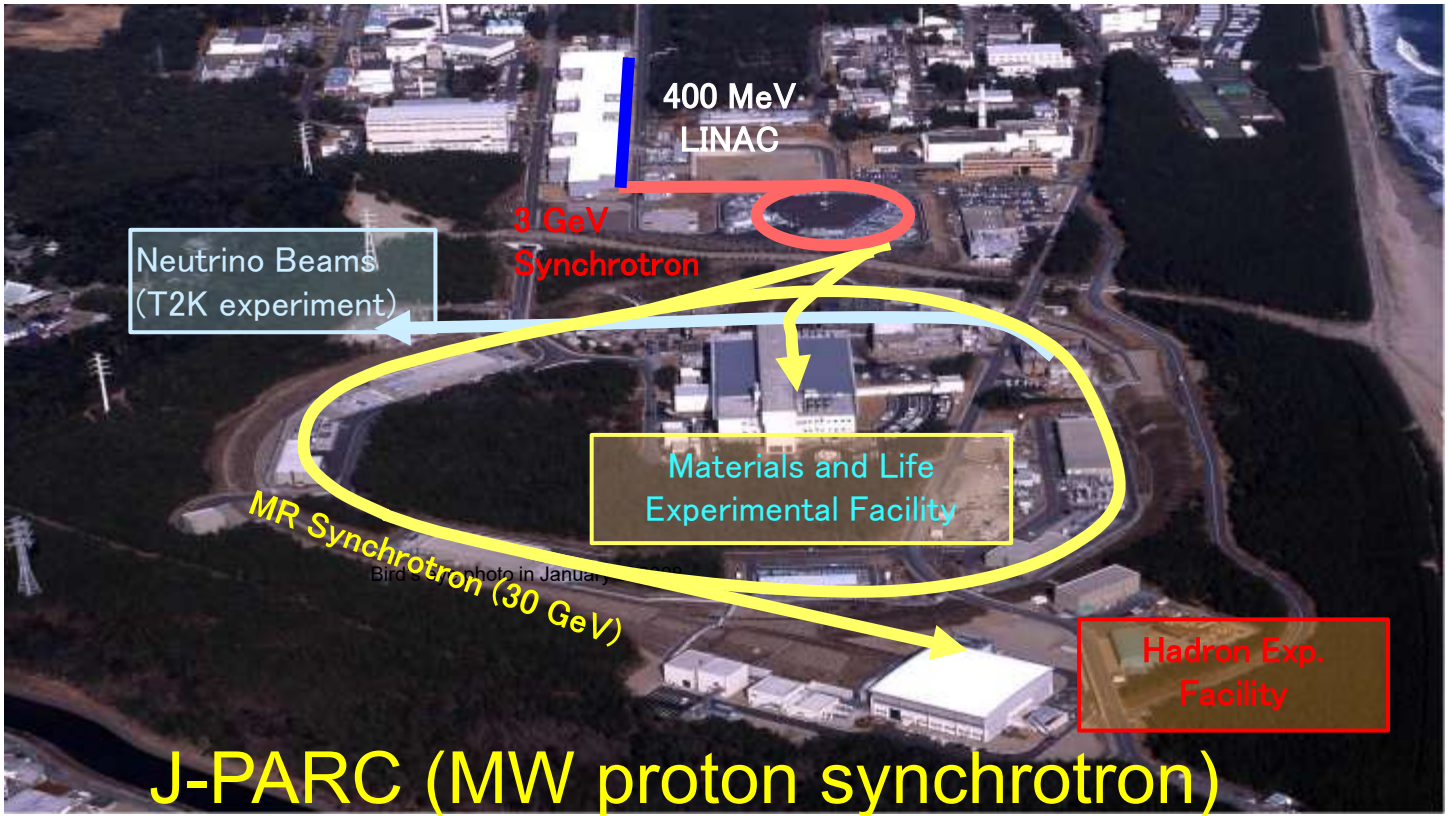


Hybrid Baryons in LQCD

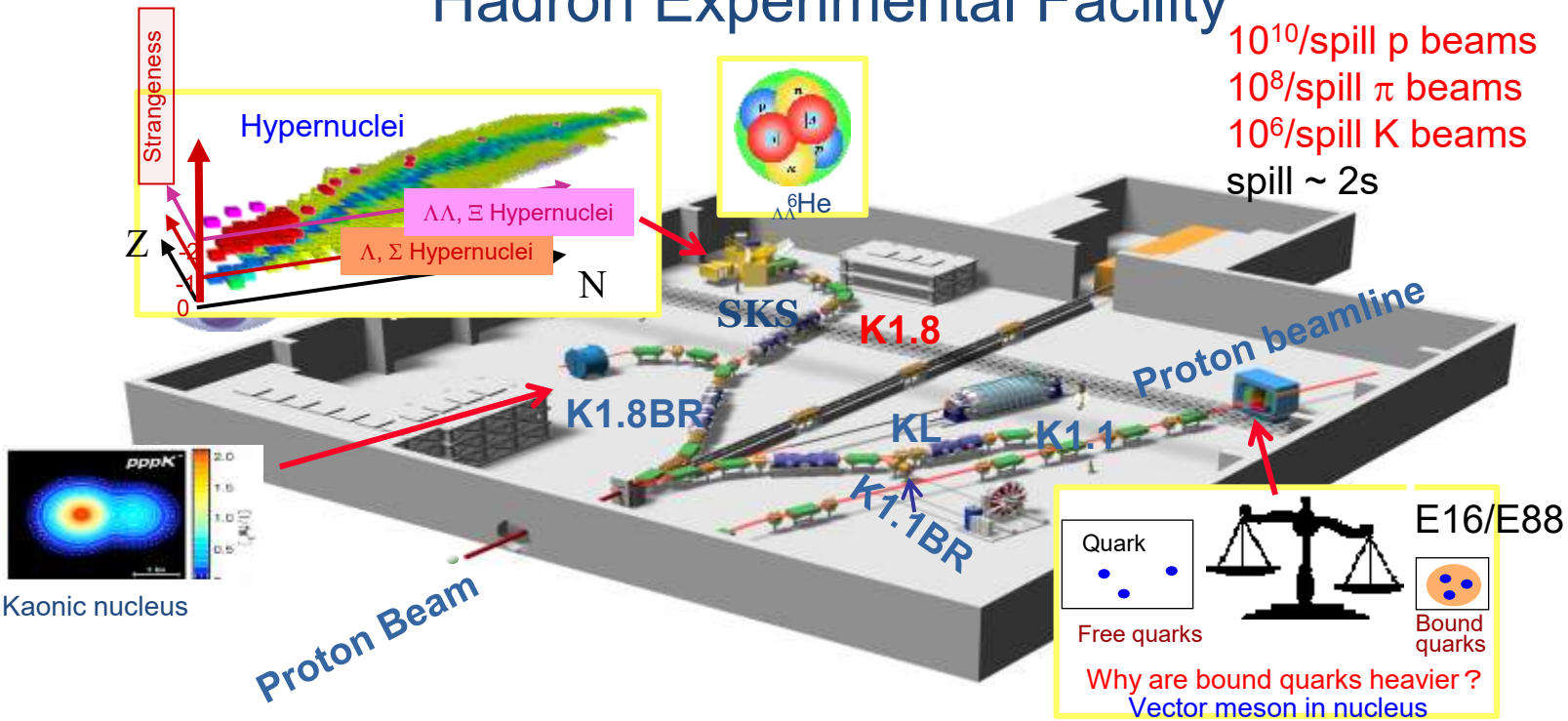
J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012)



J-PARC Accelerator Complex



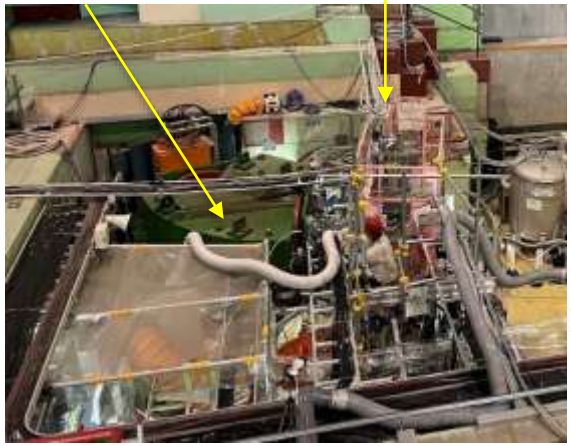
Hadron Experimental Facility



10^{10}/spill p beams
10^{8}/spill π beams
10^{6}/spill K beams
spill ~ 2s

K1.8/K1.8BR beamlines

K1.8BR Hyperon Spectrometer

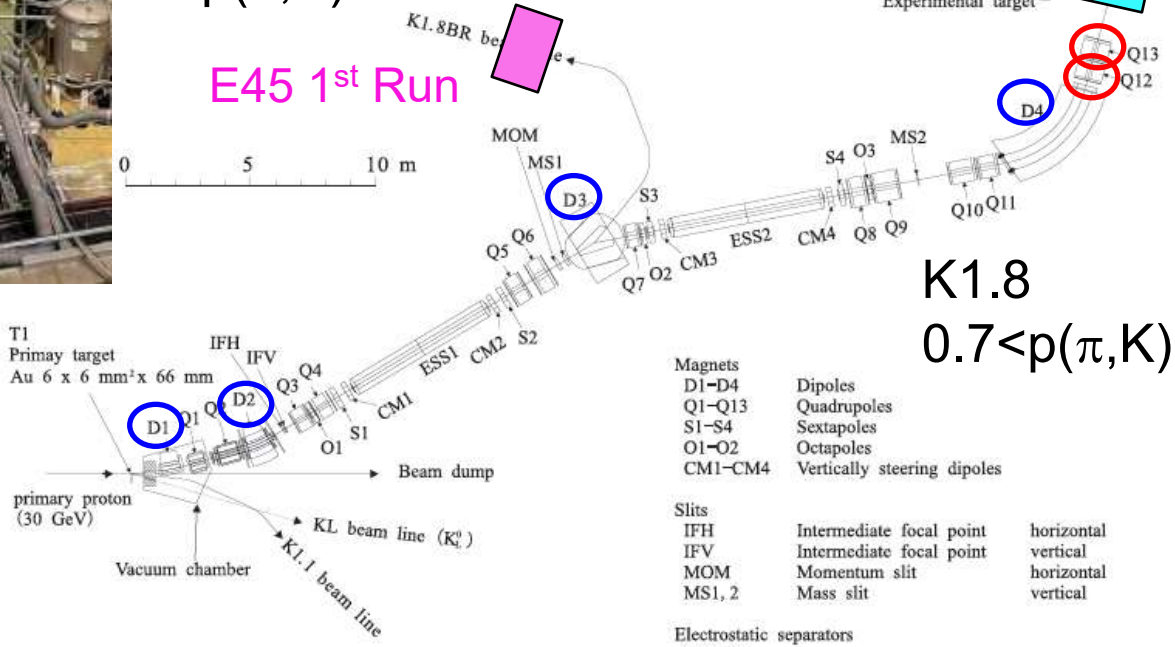


K1.8BR
p(π,K)<1.15 GeV/c

E45 1st Run

E45

K1.8
0.7<p(π,K)<2.0 GeV/c



Magnets		
D1–D4	Dipoles	
Q1–Q13	Quadrupoles	
S1–S4	Sextapoles	
O1–O2	Octapoles	
CM1–CM4	Vertically steering dipoles	
Slits		
IFH	Intermediate focal point	horizontal
IFV	Intermediate focal point	vertical
MOM	Momentum slit	horizontal
MS1, 2	Mass slit	vertical
Electrostatic separators		
ESS1, 2		

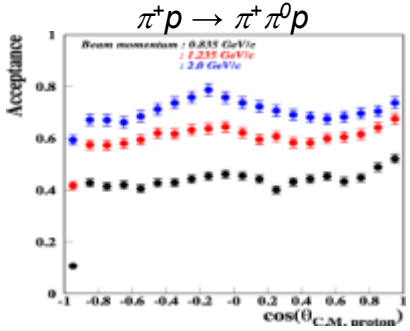
E45 setup

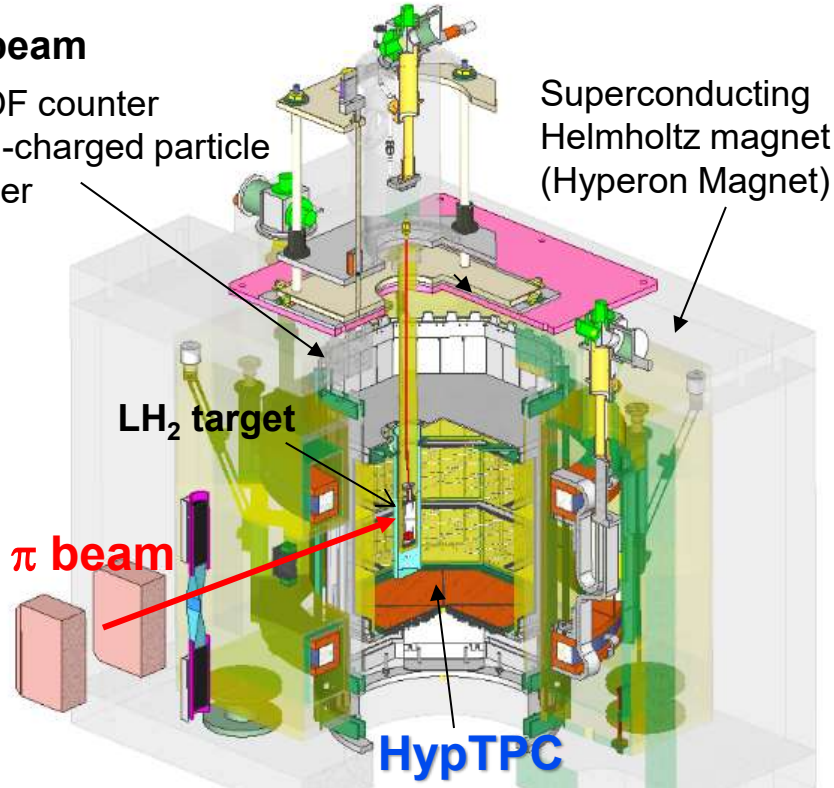
N* and Δ* spectroscopy through
measurements of (π,2π) in the large acceptance Hyperon Spectrometer

Same setup as E72/E104 except for the beam

$\pi^{+/-}$ beam on liquid-H_2 target
$\pi^- p \rightarrow \pi^+ \pi^- n,\ \pi^0 \pi^- p$
$\pi^+ p \rightarrow \pi^0 \pi^+ p,\ \pi^+ \pi^+ n$
$\pi p \rightarrow K\Lambda,\ K\Sigma$

Large acceptance ~60% for ππN reactions
w/ full coverage in θ_{cm}





Hyperon Spectrometer

2022

E42 H-dibaryon search in 2021

- W. Jung, Sep. 8, Parallel A, 18:35-18:55

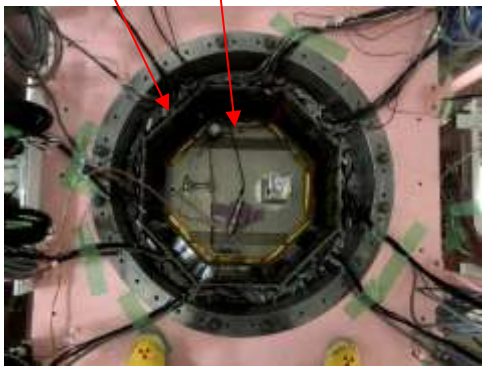
Nov. 2025, Apr. 2026

E72 $\Lambda(1665)$ study in $K^-p \rightarrow \Lambda\eta$

- S. Hayakawa, Sep. 8, Parallel A, 18:55-19:15
- Haein Lee, Sep. 10, Parallel A, Sep.10, 19:35-19:55)

Nov.-Dec. 2026

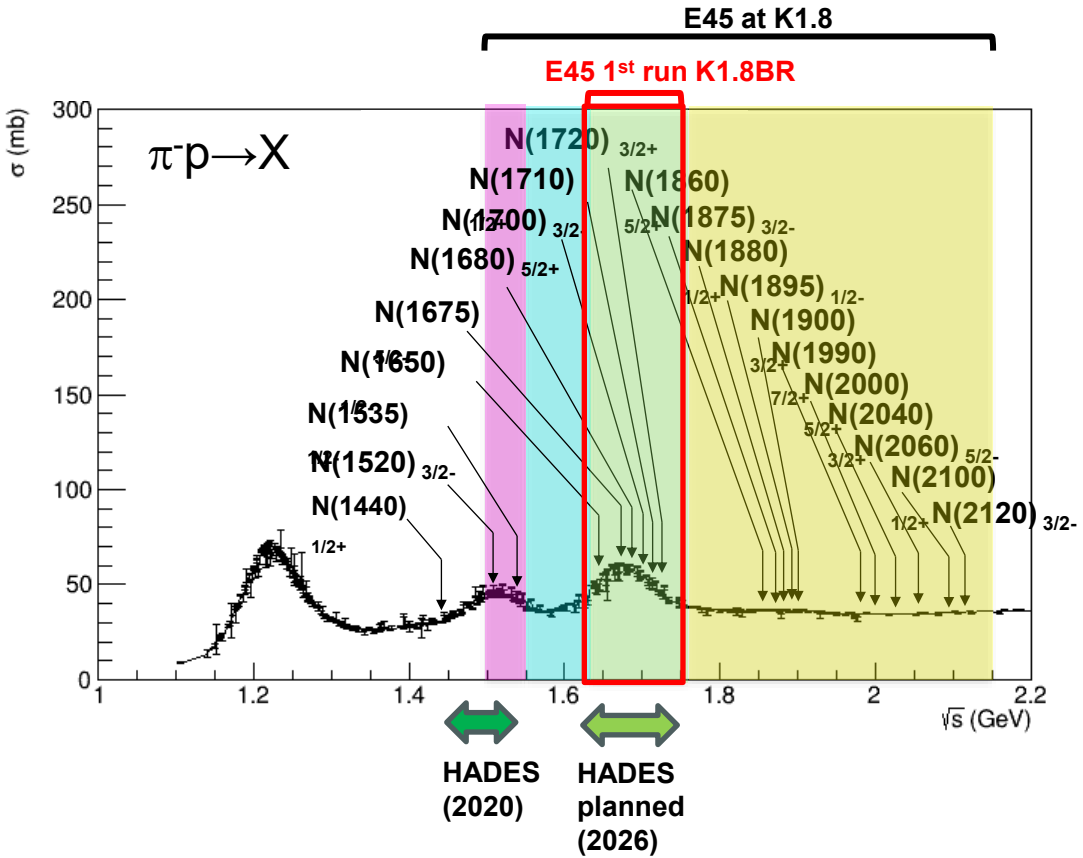
- E72
- E104 Double-ϕ production with antiproton beam
- E45 1st Run



The first E45 experiment at low-energy in Nov.-Dec. 2026

- E45 run in a low beam momentum range at K1.8BR around the 3rd resonance region.
- π+ and π- beams at W=1.66-1.76 GeV for 2.5 days
  - Several not-well-established resonances
  - Poor existing $\pi\pi$N, KΛ and KΣ data
  - Pentaquark candidate: narrow N(1720) resonance
  - HADES plans to perform an experiment with π- beam in 2026

π^-p cross sections



Δ*s also contribute (but not included in this figure)

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***						
$N(1520)$	$3/2^-$	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*				
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*			
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*			
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*		
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*	

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
$\Delta(1232)$	$3/2^+$	****	****	****				
$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		

PDG2024

What can E45 study in the first run?

- N(1700) and Δ(1750)
- Branching ratios to $\pi\pi$N not well known
  - $\Delta\pi$, Nσ, Nρ
- Low statistics for the current world's data for ΛK, ΣK
  - Possible discovery of new resonances with high-statistics data at E45

E45 Run Plan

$\sqrt{s}$ (MeV)	P (MeV/c)	π- beam time (h)	π+ beam time (h)	Ntotal ($\pi^-\pi^+n$) (k)	Ntotal ($\pi^0\pi^-p$) (k)	Ntotal ($\pi^0\pi^+p$) (k)	Ntotal ($\pi^+\pi^+n$) (k)	Ntotal ($K^0\Lambda$) (k)	Ntotal ($K^0\Sigma^0$) (k)	Ntotal ($K^+\Sigma^-$) (k)	Ntotal ($K^+\Sigma^+$) (k)
2150	1979	2.96	4	1205	800	1564	800	23	15	12	82
2125	1922	2.96	4	1205	800	1564	800	24	17	14	101
2100	1865	2.96	4	1203	800	1587	800	24	17	15	90
2075	1810	2.96	4	1203	800	1587	800	22	17	20	107
2050	1754	2.96	4	1203	800	1587	800	20	17	21	115
2025	1700	2.96	4	1185	800	1610	800	21	18	24	122
2000	1646	2.96	4	1185	800	1610	800	24	18	27	120
1970	1583	2.96	4	1183	800	1634	800	32	16	35	131
1940	1520	2.96	4	1183	800	1634	800	33	16	35	153
1910	1458	2.75	4.22	1101	800	1724	800	41	22	31	156
1870	1377	2.94	4.69	1154	800	1943	800	37	26	31	156
1830	1298	3.14	6.14	1149	800	2365	800	39		33	161
1790	1220	2.96	9.01	1082	800	3526	800	69		39	140
1750	1144	2.54	8.95	1034	800	3906	800	61		34	95
1734	1114	2.26	10.2	1029	800	5118	800	76		15	73
1702	1055	2.16	8.6	1094	800	4819	800	99		4	43
1685	1025	2.12	7.45	1113	800	4456	800	71			
1651	964	2.2	7.25	1171	800	4408	800	49			
1634	933	2.34	7.53	1005	800	4489	800	12			
1616	902	2.52	7.53	1147	800	3996	800				
1598	870	2.73	8.83	1092	800	4106	800				
1565	814	2.86	12.8	951	800	5133	800				
1536	765	2.77	18.5	851	800	6846	800				
1518	735	2.76	23.8	810	800	8403	800				

- Total 30M $\pi\pi$N events
- 800k events at each energy for PWA

1st E45 run at K1.8BR

E45 beam time and expected statistics in Nov.-Dec. 2026

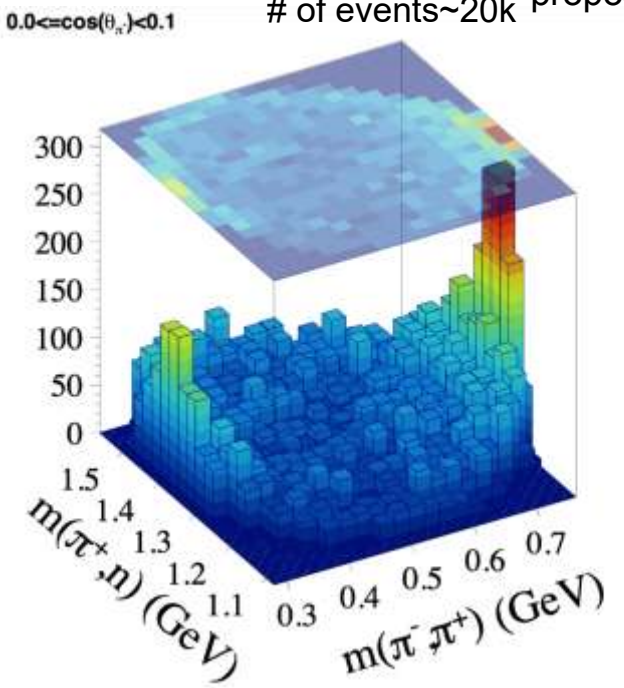
$\sqrt{s}$ (MeV)	P (MeV/c)	π- beam time (h)	π+ beam time (h)	Ntotal (π-π+n) (k)	Ntotal (π0π–p) (k)	Ntotal (π0π+p) (k)	Ntotal (π+π+n) (k)	Ntotal ($K^0\Lambda$) (k)	Ntotal ($K^+\Sigma^-$) (k)	Ntotal ($K^+\Sigma^+$) (k)
1750	1144	2.54	8.95	1034	800	3906	800	61	34	95
1734	1114	2.26	10.2	1029	800	5118	800	76	15	73
1702	1055	2.16	8.6	1094	800	4819	800	99	4	43
1685	1025	2.12	7.45	1113	800	4456	800	71		
1651	964	2.2	7.25	1171	800	4408	800	49		

- 2.5-day beam time
- 8M ππN events in the first run (30M in total at E45 with other energy ranges (1518-2150 MeV))
- 800k ππN events at each energy for PWA
- 4k~100k events for KΛ and KΣ channels

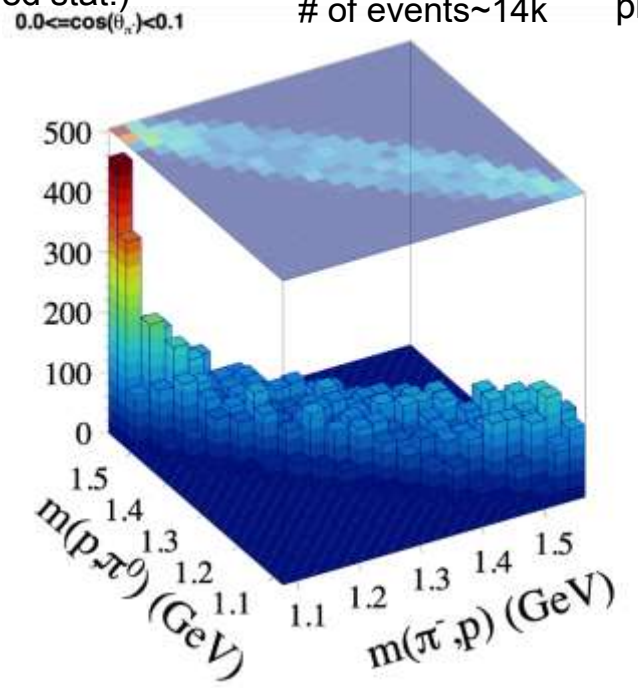
E45's statistics in a single (W, cos(theta)) bin for each reaction

Typical Dalitz plots for a specific bin at W=1.702 GeV and $0<\cos(\theta_{\pi^-}) < 0.1$

π-p → π-π+n # of events~20k — 430k (3/7 of proposed stat.)



π-p → π-pπ0 # of events~14k — 340k (3/7 of proposed stat.)



Narrow resonances N(1686) and N(1720)

(A. Gridnev et al, PRC 93 (2016) 062201(R))

- $\pi^-p \rightarrow \pi^-p$ elastic cross sections in EPECUR require narrow resonances N(1686)S_{11} and N(1720)P_{11}. The latter could be a candidate for a pentaquark with $\bar{s}s$.
- High statistics $\pi^-p \rightarrow K^0\Lambda$ and $\pi^-p \rightarrow \eta n$ data are necessary to establish these narrow resonances.
- E45 will measure $\pi^-p \rightarrow K^0\Lambda$ with much higher statistics (10-100k) than the current world's dataset.

$\pi^-p \rightarrow \pi^-p$

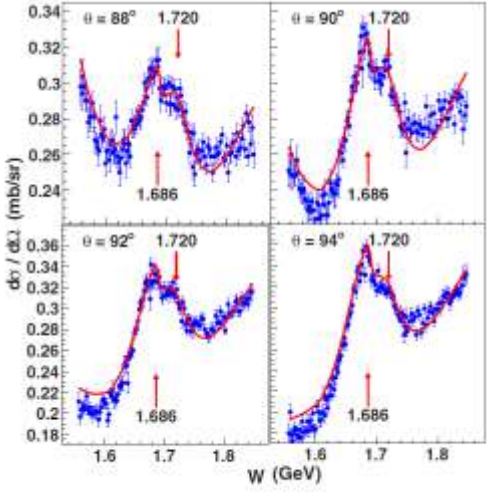


FIG. 4. $\pi^- p$ elastic scattering with added resonances. The red solid line gives the present calculation.

$\pi^-p \rightarrow K^0\Lambda$

Prediction from π-p → π-p data

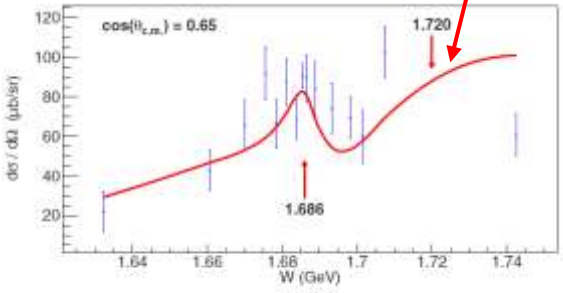
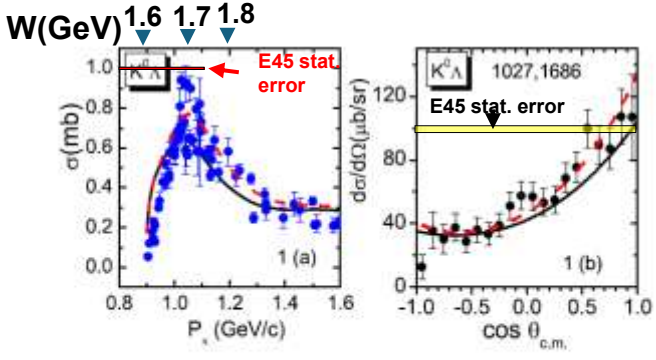


FIG. 7. Energy dependence of $\pi^- p \rightarrow K\Lambda$ differential cross section. Red solid line indicates present calculations.

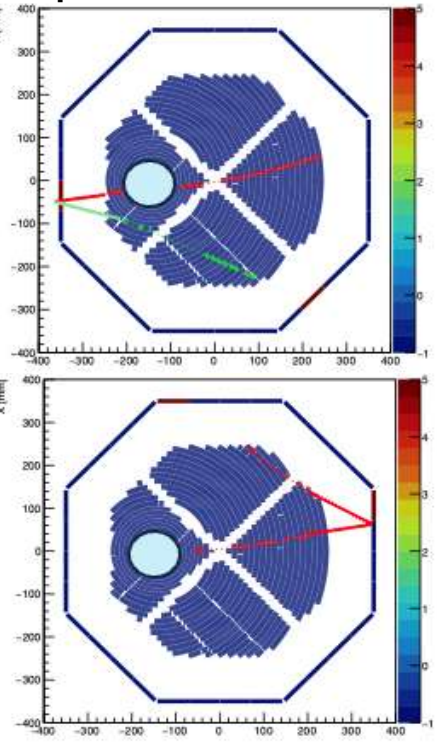
Existing $\pi^-p \rightarrow K^0\Lambda$ data (PRC 94, 035202 (2016))



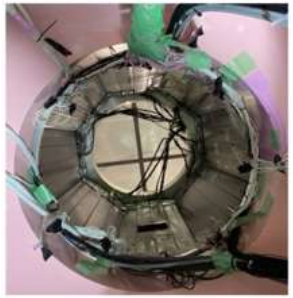
Trigger Study in April 2026

Trigger rate ~3 k/spill at 300k/spill π- beam rate achieved.

Background events with reactions on upstream or downstream HTOF



HTOF



Background suppression

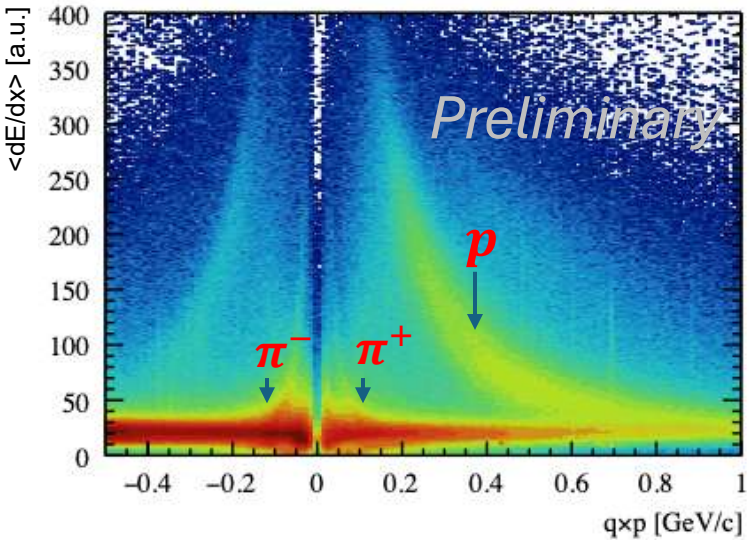
- ☑ Upstream HTOF, T1, and SCH
- ☑ HTOF downstream adjacent segments to reject beam-through events

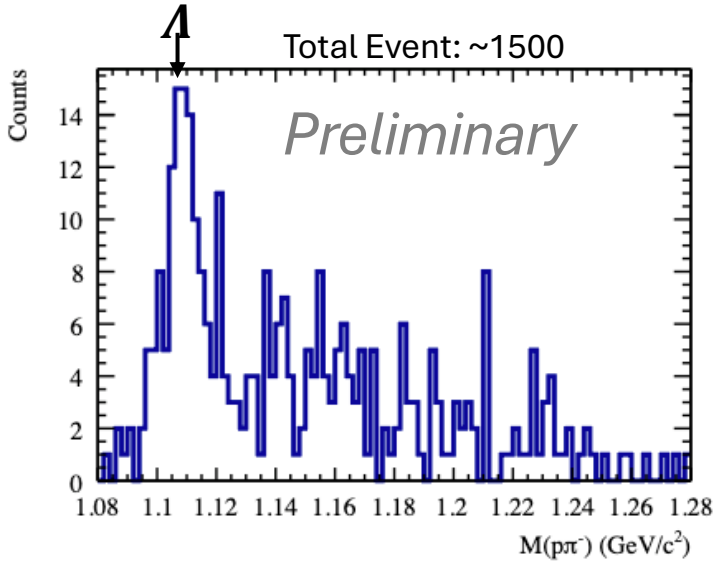
Achieved ~3k/spill trigger rate at 300 k/spill beam rate

Preliminary analysis results in Nov. 2025

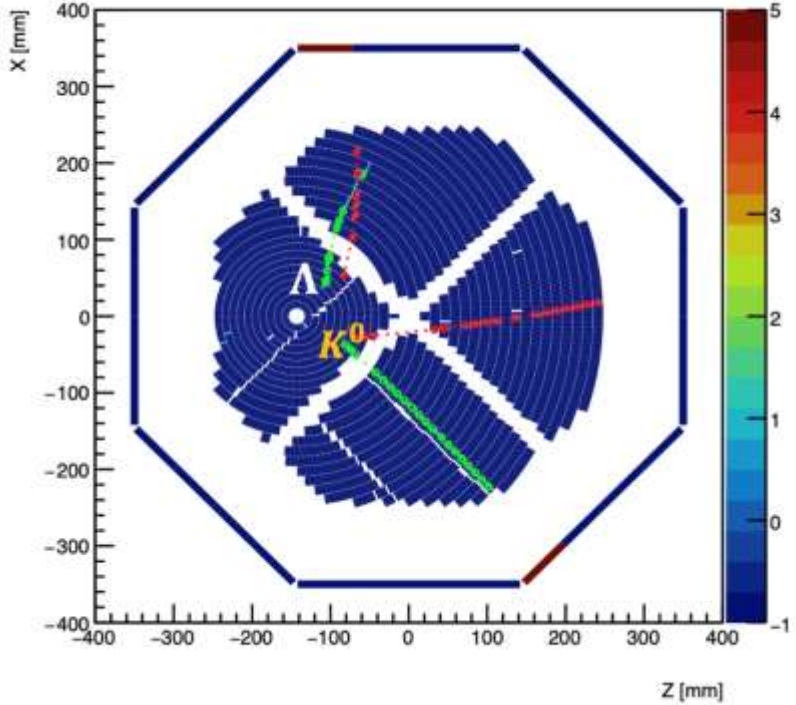
Data Set:
- **Beam: π^-, 1.0 GeV/c**
- Trigger: HTOF Multipliciy ≥ 3
- Total Events: ~ 6 M

Λ Selection:
1. Select p, π^- via <dE/dx> **PID**
2. Track Multiplicity: positive 2/ negative 2 ($\pi^- p \rightarrow K^0 \Lambda$)
3. For Λ and K^0 decays: DCA < 10 mm
4. K^0 mass cut: 480 < M_{K^0} < 510 MeV/c^2





$\pi^- p \rightarrow K^0 \Lambda$ event candidate



Summary

- E45 studies N* and Δ* resonances with $\pi N \rightarrow \pi\pi N$ reactions, which enhances the world's data statistics by a factor of ~100.
- The first low-energy run of E45 will be performed at K1.8BR to cover the 3rd resonance region in Nov.-Dec. 2026.
  - 2.5 days after E72/E104
- Global collaboration between E45 and HADES for the partial-wave analysis is underway for these two complementary experiments.