

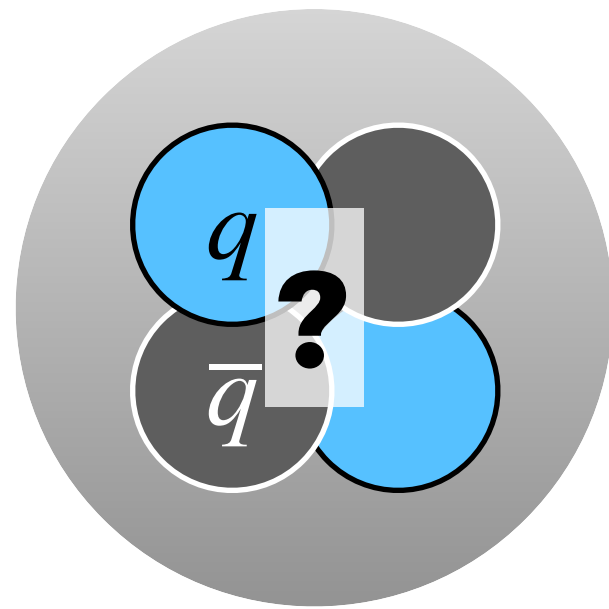
Hadron Physics with Kaon Beams at the J-PARC K1.8BR and K1.8 Beam Lines

Shuhei Hayakawa
Tohoku University

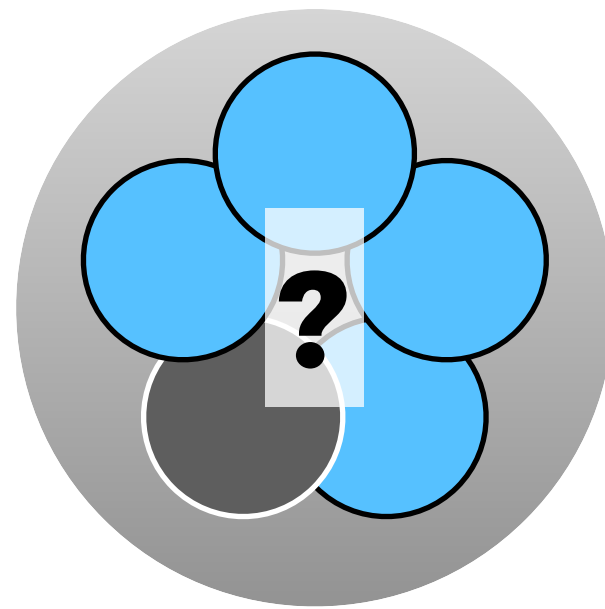
New Perspectives on exotic and heavy hadrons, 25–28 Aug 2026, Inha University

Exotic hadrons and hadron structure

Heavy-quark sector

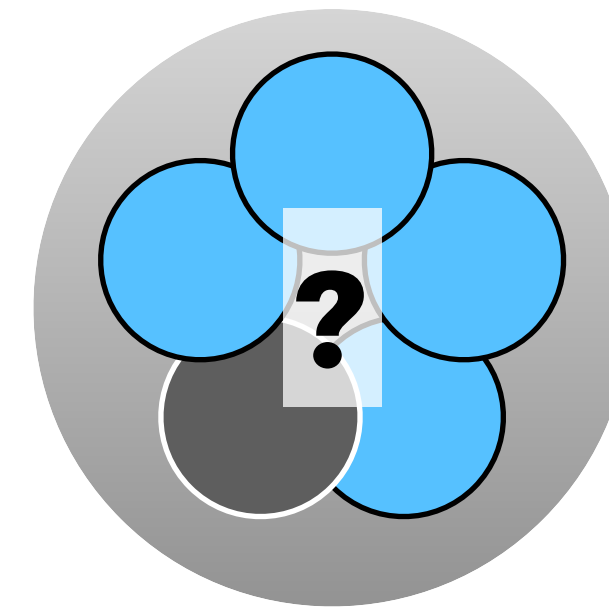


$X(3872), T_{cc}$



P_c

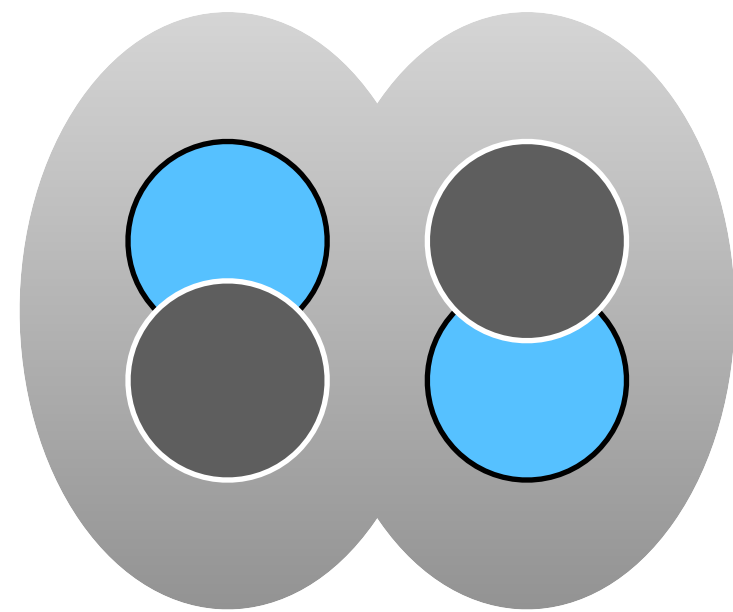
Strange sector



$\Lambda(1405)$

Exotic hadrons and hadron structure

Heavy-quark sector

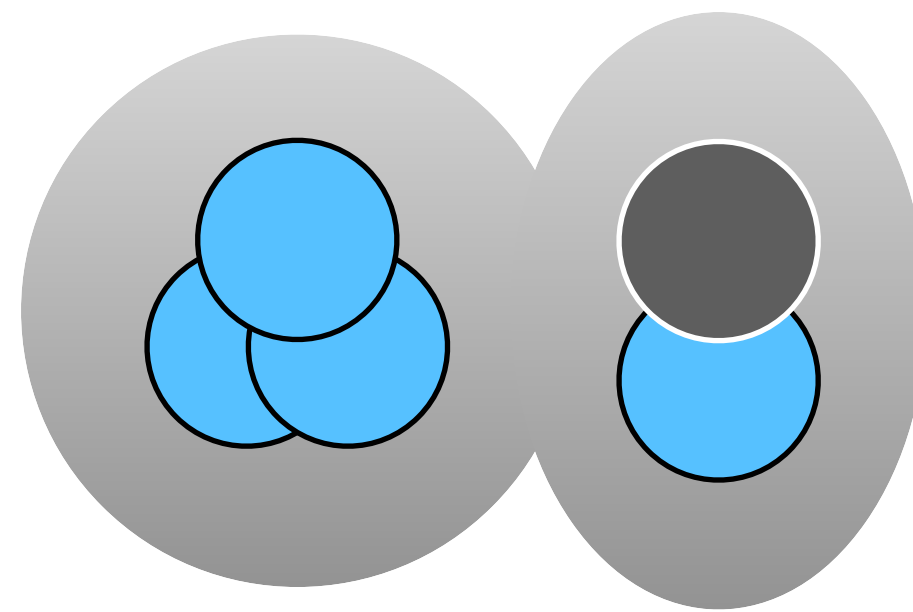


$X(3872), T_{cc}$

$D\bar{D}^*$

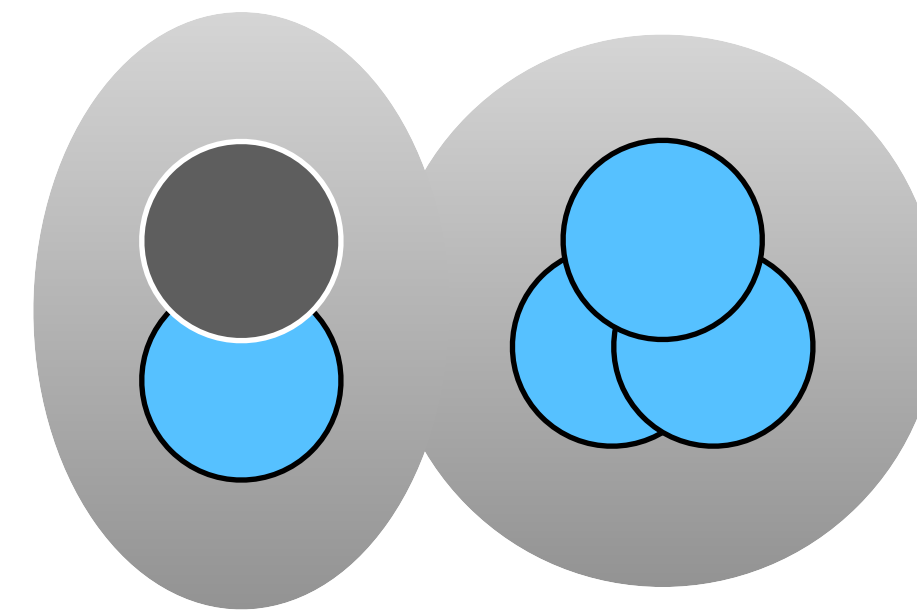
DD^*

$\Sigma_c \bar{D}^{(*)}$



P_c

Strange sector



$\Lambda(1405)$

$\bar{K}N \leftrightarrow \pi\Sigma$

Many exotic candidates lie close to hadron-hadron thresholds.

Hadron spectroscopy is a key to understanding exotic hadron structure.

Present Λ^*/Σ^* resonances

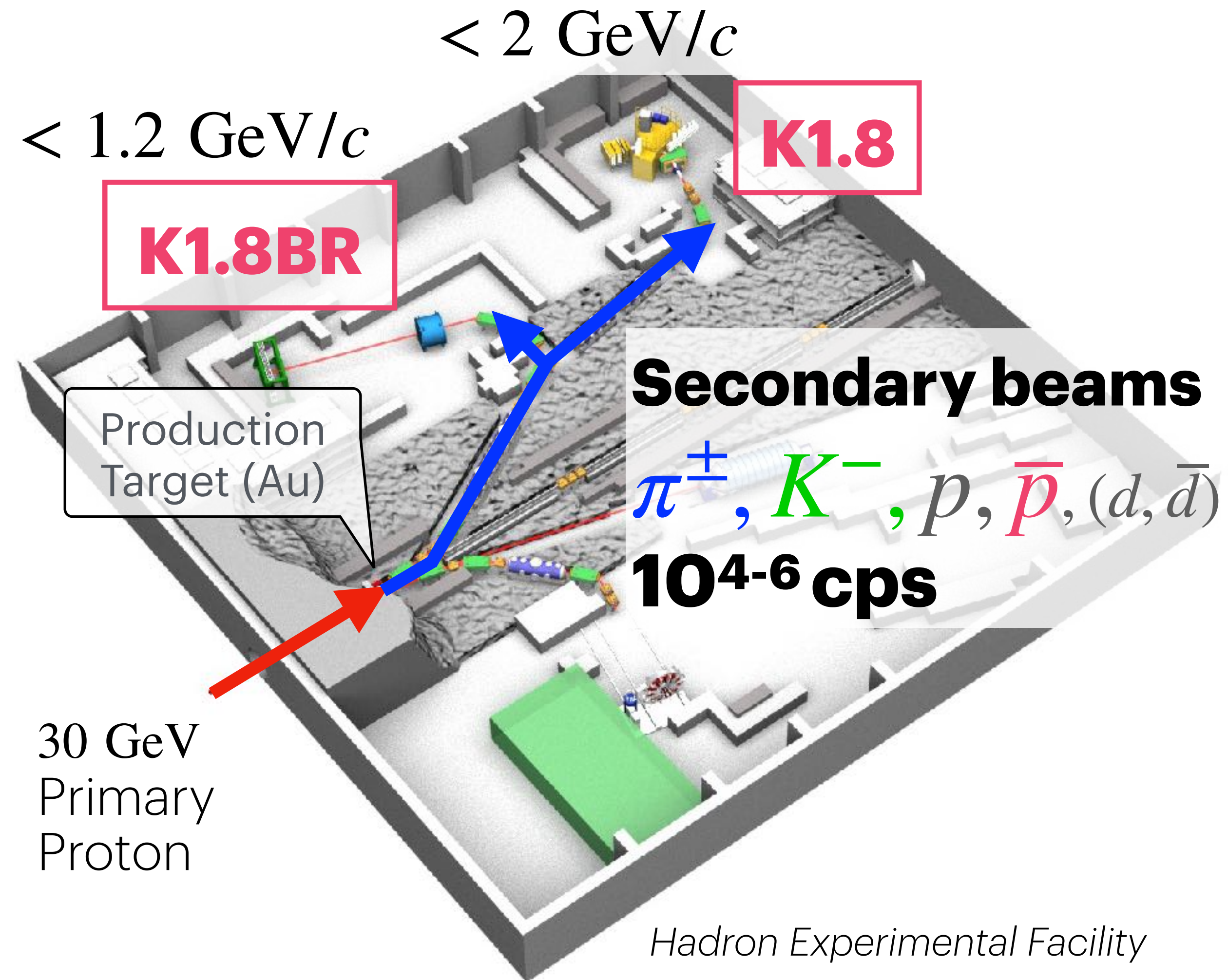
PDG2026

Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\bar{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\bar{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\bar{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*		
$\Lambda(2350)$	$9/2^+$	***	***	*	
$\Lambda(2585)$		*	*		

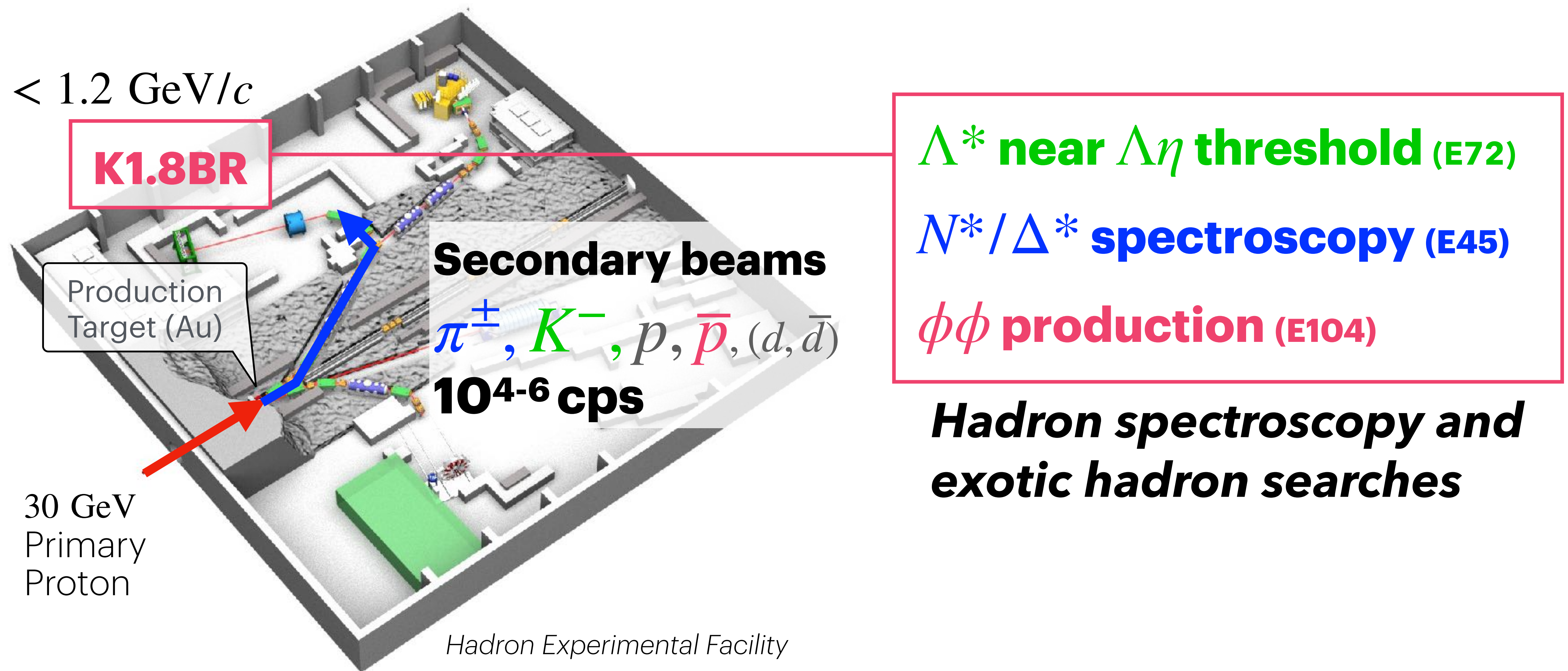
Particle	J^P	Overall status	Status as seen in —			Other channels
			$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	
$\Sigma(1193)$	$1/2^+$	****				$N\pi$ (weak decay)
$\Sigma(1385)$	$3/2^+$	****		****	****	$\Lambda\gamma$
$\Sigma(1580)$	$3/2^-$	*	*	*	*	
$\Sigma(1620)$	$1/2^-$	*	*	*	*	
$\Sigma(1660)$	$1/2^+$	***	***	***	***	
$\Sigma(1670)$	$3/2^-$	****	****	****	****	
$\Sigma(1750)$	$1/2^-$	***	***	**	***	$\Sigma\eta$
$\Sigma(1775)$	$5/2^-$	****	****	****	**	
$\Sigma(1780)$	$3/2^+$	*	*	*	*	
$\Sigma(1880)$	$1/2^+$	**	**	*		
$\Sigma(1900)$	$1/2^-$	**	**	*	**	
$\Sigma(1910)$	$3/2^-$	***	*	*	**	
$\Sigma(1915)$	$5/2^+$	****	***	***	***	
$\Sigma(1940)$	$3/2^+$	*	*		*	
$\Sigma(2010)$	$3/2^-$	*	*	*		
$\Sigma(2030)$	$7/2^+$	****	****	****	**	$\Delta(1232)\bar{K}, N\bar{K}^*, \Sigma(1385)\pi$
$\Sigma(2070)$	$5/2^+$	*	*		*	
$\Sigma(2080)$	$3/2^+$	*		*		
$\Sigma(2100)$	$7/2^-$	*	*	*	*	
$\Sigma(2110)$	$1/2^-$	*	*	*	*	
$\Sigma(2230)$	$3/2^+$	*	*	*	*	
$\Sigma(2250)$		**	**	*	*	
$\Sigma(2455)$		*	*			
$\Sigma(2620)$		*	*			
$\Sigma(3000)$		*	*	*		
$\Sigma(3170)$		*				

More than half are still poorly established

J-PARC Hadron Experimental Facility

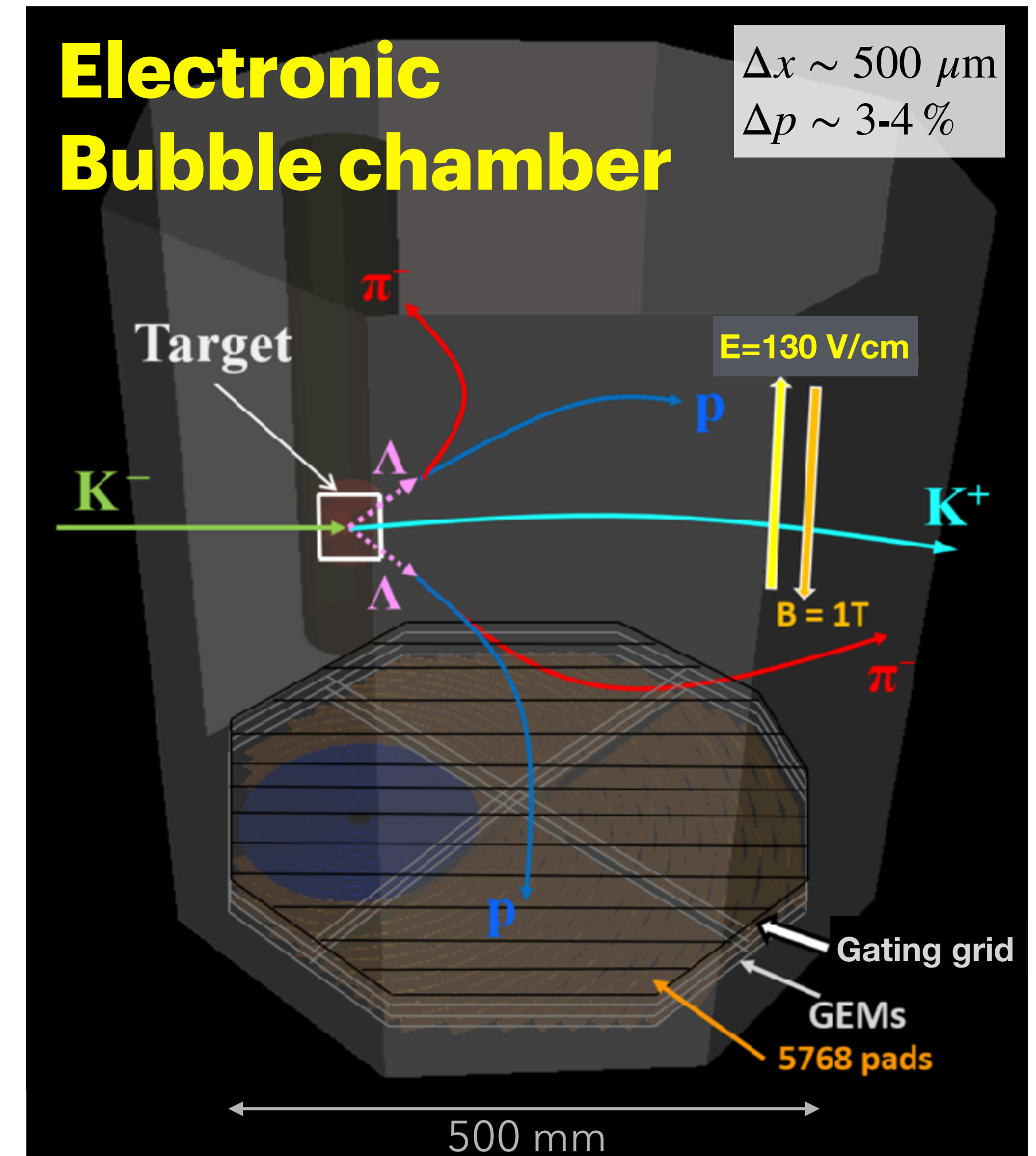
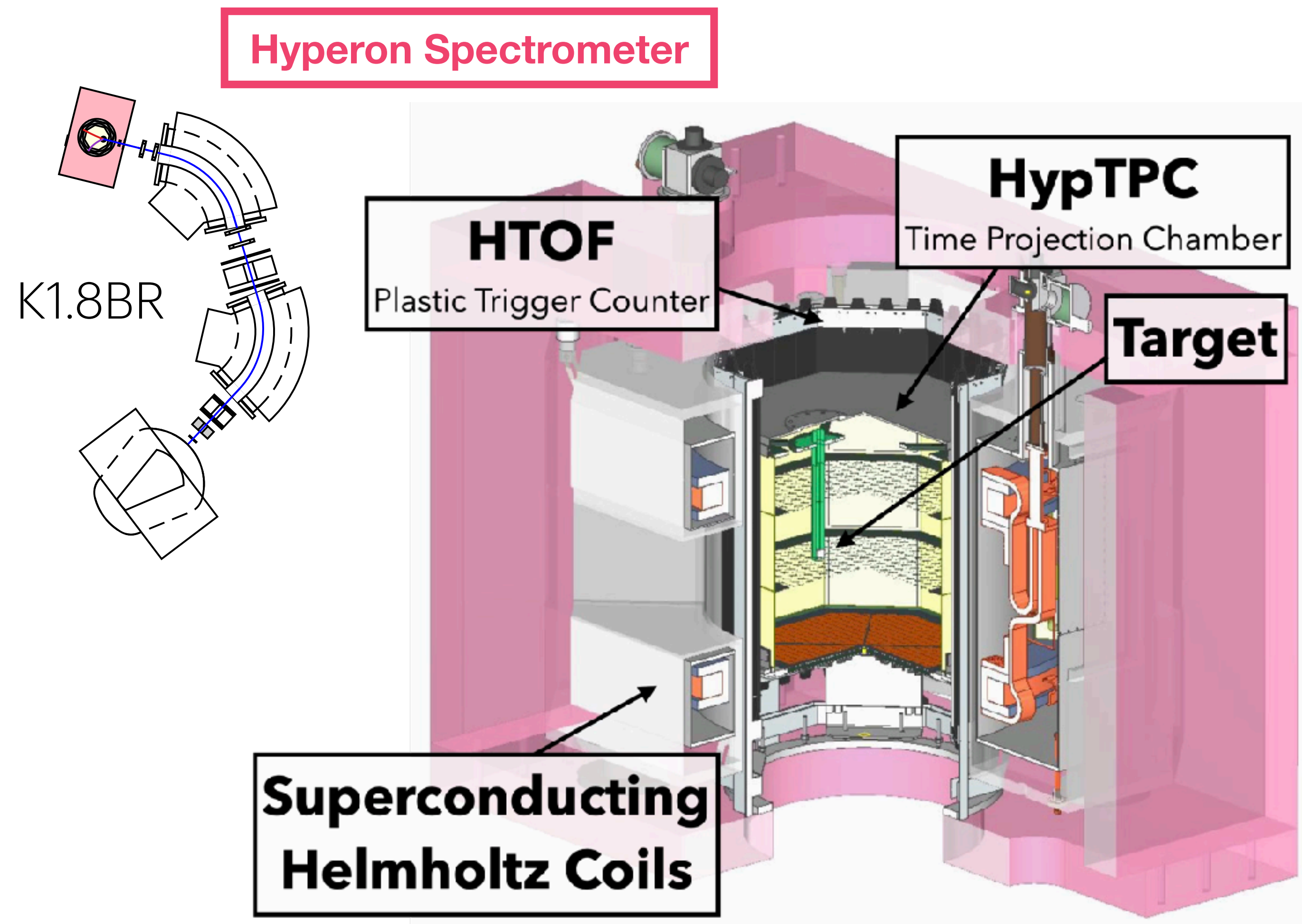


J-PARC Hadron Experimental Facility



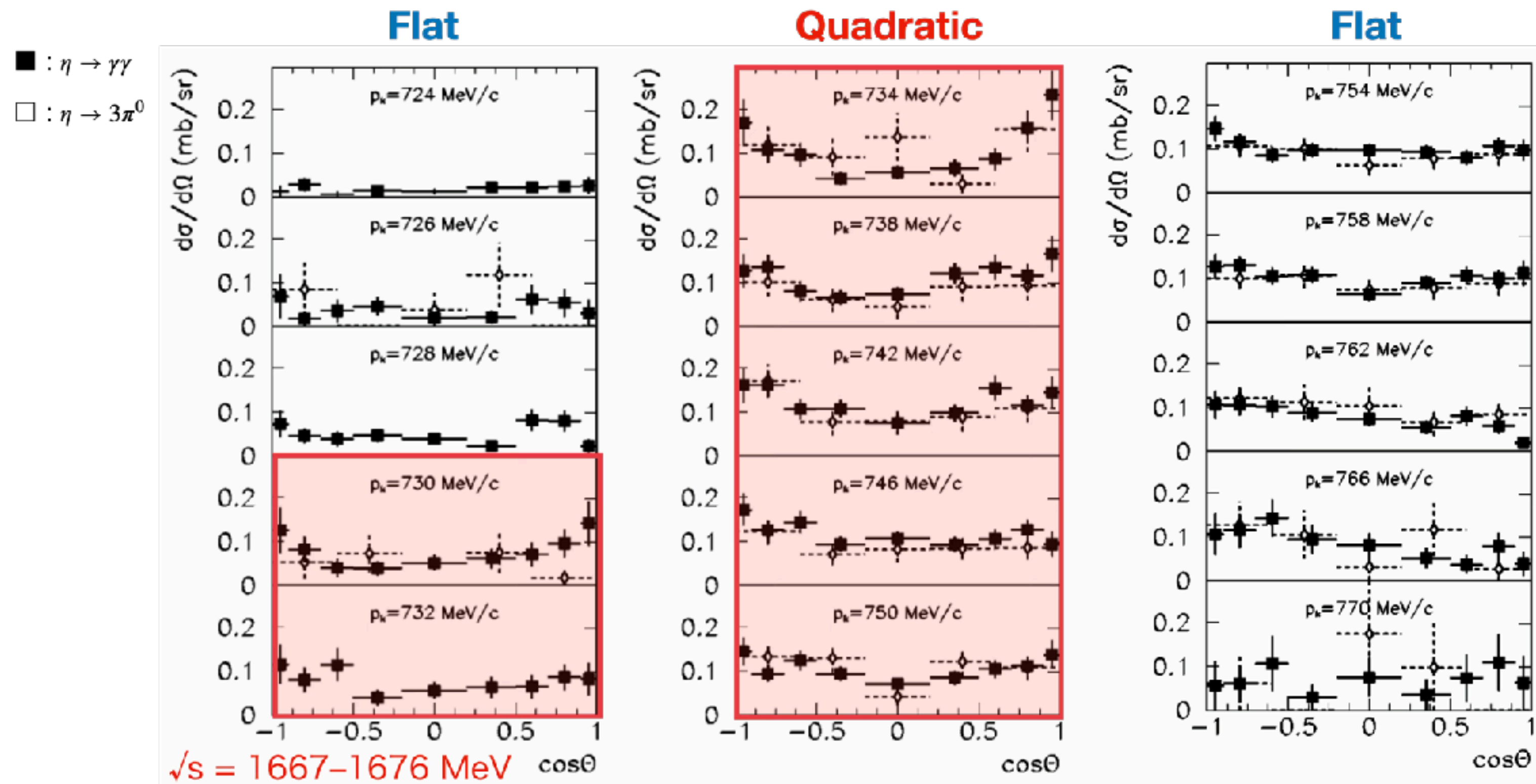
Hyperon Spectrometer / HypTPC

Reconstruction of charged multi-particle final states



Search for Narrow Λ^* J=3/2 near $\Lambda\eta$ threshold (E72)

Extra Λ^* J=3/2 indicated by past result



$K^-p \rightarrow \Lambda\eta$ measurement
with HypTPC near threshold

Accessible Λ^*/Σ^* resonances using K^-p reaction

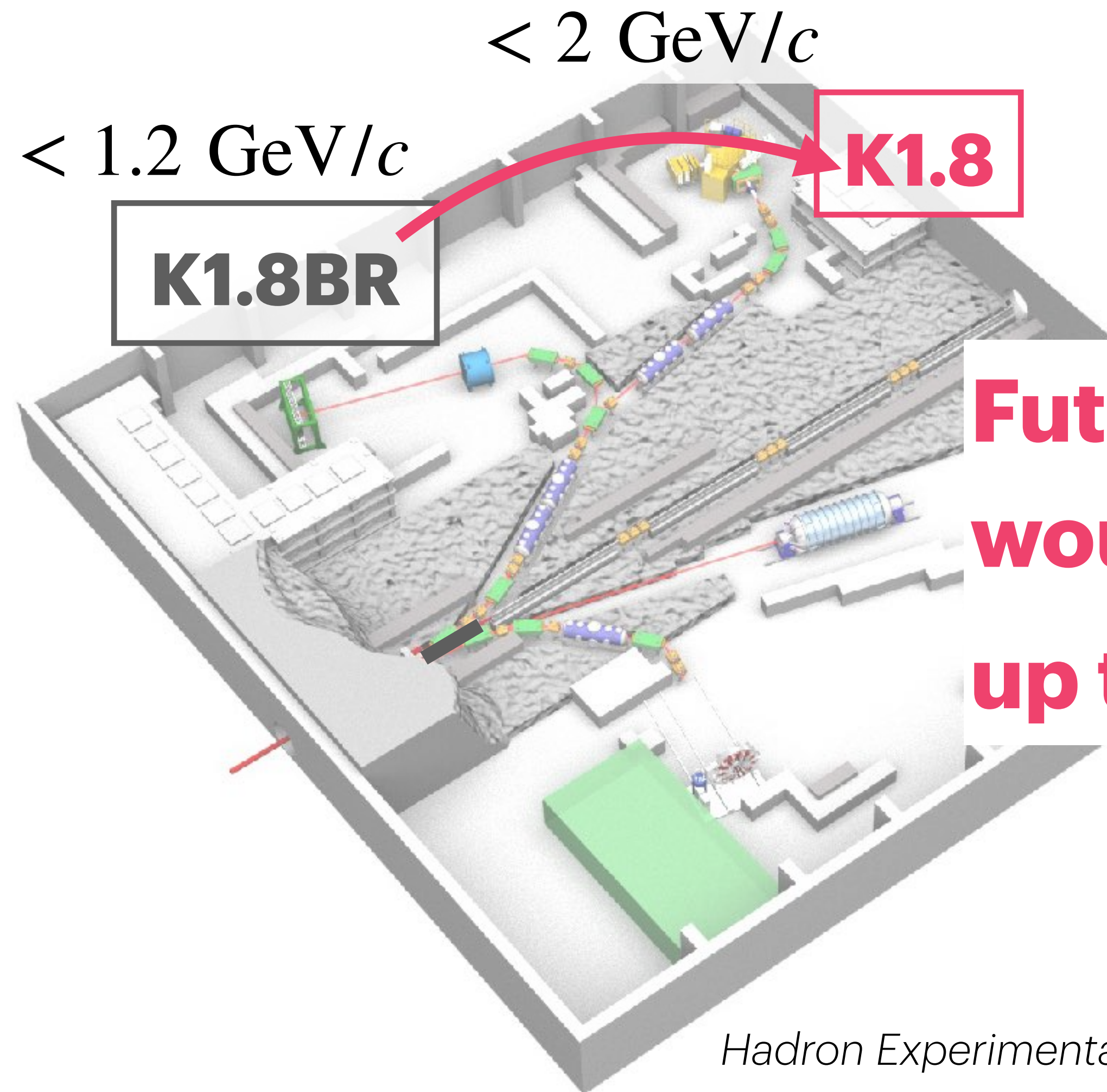
Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\bar{K}^*$

Particle	J^P	Overall status	Status as seen in —			Other channels
			$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	
$\Sigma(1193)$	$1/2^+$	****				$N\pi$ (weak decay)
$\Sigma(1385)$	$3/2^+$	****		****	****	$\Lambda\gamma$
$\Sigma(1580)$	$3/2^-$	*	*	*	*	
$\Sigma(1620)$	$1/2^-$	*	*	*	*	
$\Sigma(1660)$	$1/2^+$	***	***	***	***	
$\Sigma(1670)$	$3/2^-$	****	****	****	****	
$\Sigma(1750)$	$1/2^-$	***	***	**	***	$\Sigma\eta$
$\Sigma(1775)$	$5/2^-$	****	****	****	**	
$\Sigma(1780)$	$3/2^+$	*	*	*	*	
$\Sigma(1880)$	$1/2^+$	**	**	*		

Key opportunities at K1.8BR:

- **$\Lambda\eta$ threshold:** Narrow $\Lambda(1665)$ candidate, $\Lambda(1670)$
- **$\Sigma\eta$ threshold:** $\Sigma(1750)$
- **$\Lambda(1710)$: does it exist?**
- **$\Sigma(1670)$: structure and couplings**

Hadron spectroscopy at K1.8



**Future HypTPC program at K1.8
would extend K^-p energy coverage
up to $\sqrt{s} \simeq 2.2 \text{ GeV}$**

Hadron Experimental Facility

What can K1.8 cover?

Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\bar{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\bar{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\bar{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*		
$\Lambda(2350)$	$9/2^+$	***	***	*	

Particle	J^P	Overall status	Status as seen in —			Other channels
			$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	
$\Sigma(1193)$	$1/2^+$	****				$N\pi$ (weak decay)
$\Sigma(1385)$	$3/2^+$	****		****	****	$\Lambda\gamma$
$\Sigma(1580)$	$3/2^-$	*	*	*	*	
$\Sigma(1620)$	$1/2^-$	*	*	*	*	
$\Sigma(1660)$	$1/2^+$	***	***	***	***	
$\Sigma(1670)$	$3/2^-$	****	****	****	****	
$\Sigma(1750)$	$1/2^-$	***	***	**	***	$\Sigma\eta$
$\Sigma(1775)$	$5/2^-$	****	****	****	**	
$\Sigma(1780)$	$3/2^+$	*	*	*	*	
$\Sigma(1880)$	$1/2^+$	**	**	*		
$\Sigma(1900)$	$1/2^-$	**	**	*	**	
$\Sigma(1910)$	$3/2^-$	***	*	*	**	
$\Sigma(1915)$	$5/2^+$	****	***	***	***	
$\Sigma(1940)$	$3/2^+$	*	*		*	
$\Sigma(2010)$	$3/2^-$	*	*	*		
$\Sigma(2030)$	$7/2^+$	****	****	****	**	$\Delta(1232)\bar{K}, N\bar{K}^*, \Sigma(1385)\pi$
$\Sigma(2070)$	$5/2^+$	*	*		*	
$\Sigma(2080)$	$3/2^+$	*		*		
$\Sigma(2100)$	$7/2^-$	*	*	*	*	
$\Sigma(2110)$	$1/2^-$	*	*	*	*	
$\Sigma(2230)$	$3/2^+$	*	*	*	*	
$\Sigma(2250)$		**	**	*	*	

Many states are still poorly established

Why are they still poorly known?

**Most $\bar{K}N$ data are old and incomplete,
especially for multi-body final states and polarization observables.**

$$K^-p \rightarrow \bar{K}N, \pi\Lambda, \pi\Sigma$$

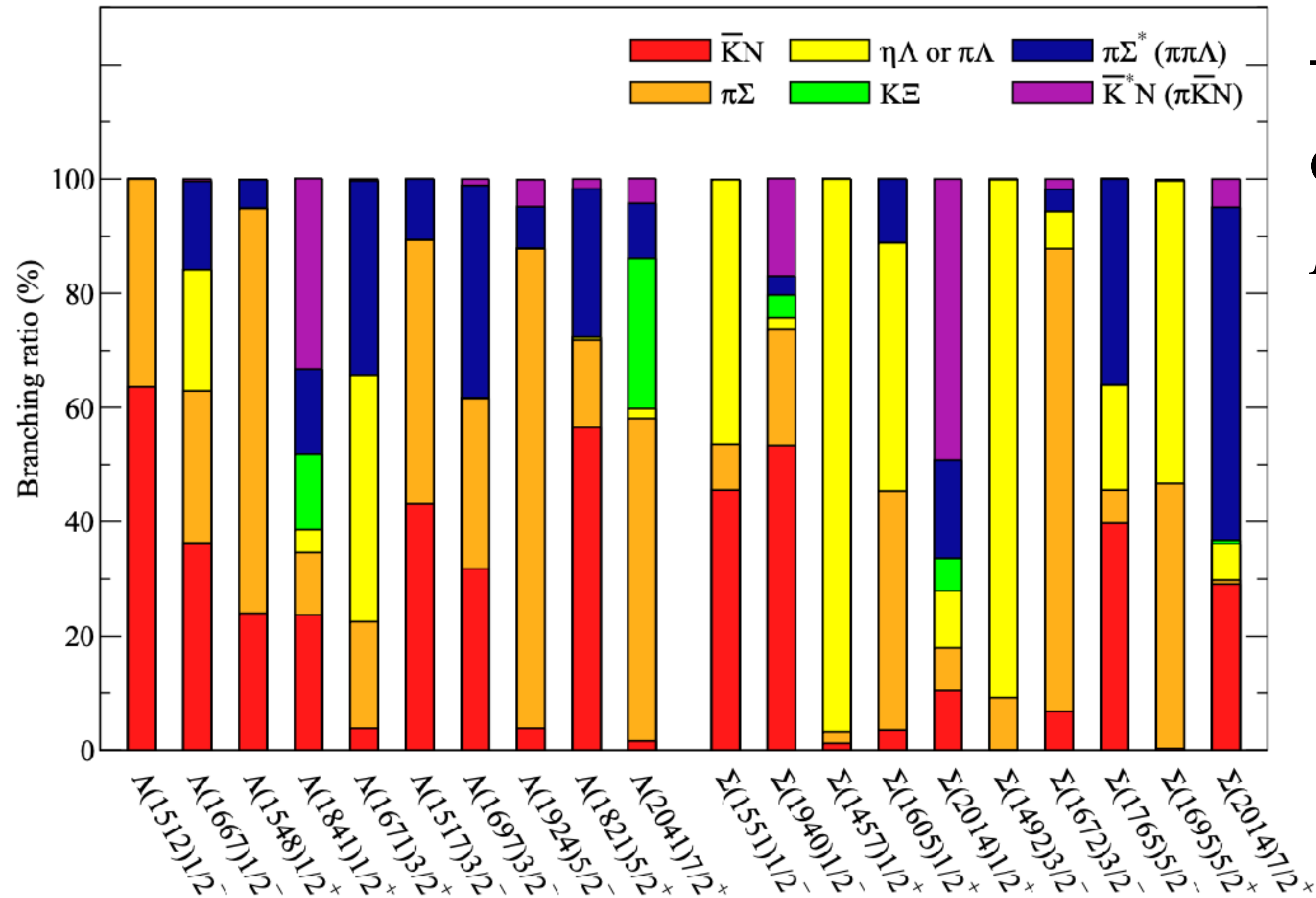
low-mass

$$K^-p \rightarrow \pi\Sigma(1385), \pi\Lambda(1520), \bar{K}^*N, K\Xi, \dots$$

high-mass

Measure couplings, not only peaks

PRC 92, 025205 (2015)



The calculation predicts many channel couplings other than $\bar{K}N$ and $\pi\Sigma$.

Multi-body spectroscopy with HypTPC

$$\begin{aligned} K^- p &\rightarrow \pi^- \Sigma(1385)^+ \\ &\rightarrow \pi^- \pi^+ \Lambda \rightarrow \pi^- \pi^+ p \pi^- \end{aligned}$$

all-charged final state

$$\left(\begin{array}{l} M(p\pi^-) \rightarrow \Lambda \\ M(\Lambda\pi^+) \rightarrow \Sigma(1385)^+ \\ M(\pi^- \Sigma(1385)^+) \rightarrow Y^* \end{array} \right.$$

- **Invariant masses**
- **Dalitz plots**
- **Helicity angles**
- **Λ polarization**

Amplitude information, not only resonance peaks

Physics opportunities at K1.8

- **Around 1.8 GeV**

- $KE, \bar{K}^*N$
- **Threshold / coupled-channel dynamics**

- **Around 2.0 GeV**

- $\Lambda(2070), \Lambda(2080), \Sigma(2010), \Sigma(2030)$
Newly listed as 1-star well-established reference
- **Poorly established states / qqq multiplets**
- **How do quark-model excitations and hadronic dynamics coexist?**

Ξ^* resonances

associated production: $K^-p \rightarrow K\Xi^*$

Particle	J^P	Overall status	Status as seen in —				Other channels
			$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	
$\Xi(1320)$	$1/2+$	****					Decays weakly
$\Xi(1530)$	$3/2+$	****	****				
$\Xi(1620)$		**	**				
$\Xi(1690)$	$1/2-$	***	**	***	**		
$\Xi(1820)$	$3/2-$	****	**	****	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

K1.8

→ Future K10

Summary

From hyperon spectroscopy to hadron structure

- **K1.8BR: threshold phenomena and low-mass Λ^*/Σ^***
- **K1.8: systematic Λ^*/Σ^* spectroscopy up to $\sqrt{s} \simeq 2.2$ GeV**
- **Hadron spectroscopy connects conventional qqq excitations and exotic/coupled-channel dynamics**

Further higher energy $\rightarrow$ K10