Λ^* AND Σ^* SPECTRUM FROM THE JÜLICH-BONN DCC MODEL

and other recent results

NSTAR 2026, Sevilla, September 8, 2026 | Deborah Rönchen | IAS-4 Forschungszentrum Jülich

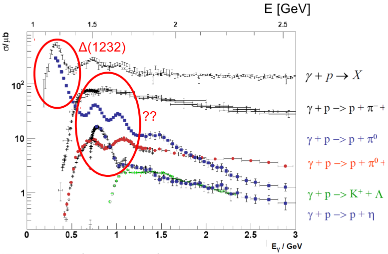
In collaboration with: M. Döring, M. Mai, T. Mart, U.-G. Meißner, C. Schneider, Y.-F. Wang, R. Workman (Jülich-Bonn-Washington collaboration)

Supported by BMFTR, DFG, HPC support by Jülich Supercomputing Centre

The excited baryon spectrum:

Connect experiment & QCD in the non-perturbative regime

Experimental study of hadronic reactions

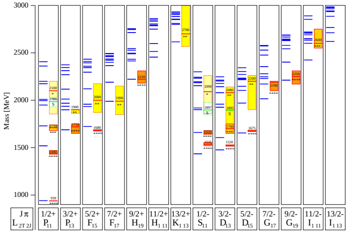


source: ELSA; data: ELSA, JLab, MAMI

Reviews: e.g Prog.Part.Nucl.Phys. 125 (2022), Prog.Part.Nucl.Phys. 111 (2020), Prog.Part.Nucl.Phys. 67 (2012)

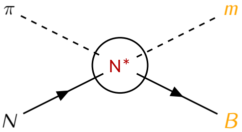
JüBo
model

Theoretical predictions of excited baryons

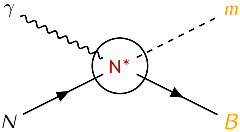


Löring *et al.* EPJ A 10, 395 (2001), experimental spectrum: PDG 2000

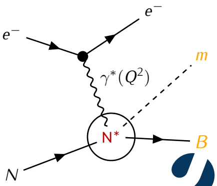
πN **scattering**



photoproduction



electroproduction



The Jülich-Bonn DCC approach: hadronic reactions

EPJ A 49, 44 (2013)

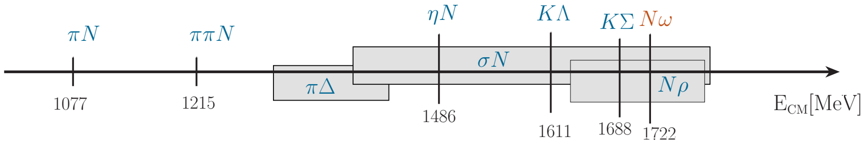
color meets flavor

Dynamical coupled-channels (DCC): **simultaneous** analysis of different reactions

The scattering equation for pion-induced reactions

$$\langle L'S'p'|T_{\mu\nu}|LSp\rangle = \langle L'S'p'|V_{\mu\nu}|LSp\rangle + \sum_{\kappa,L''S''} \int_0^\infty dq \quad q^2 \quad \langle L'S'p'|V_{\mu\kappa}|L''S''q\rangle \frac{1}{E - E_\kappa(q) + i\epsilon} \langle L''S''q|T_{\kappa\nu}|LSp\rangle$$

- channels ν, μ, κ:



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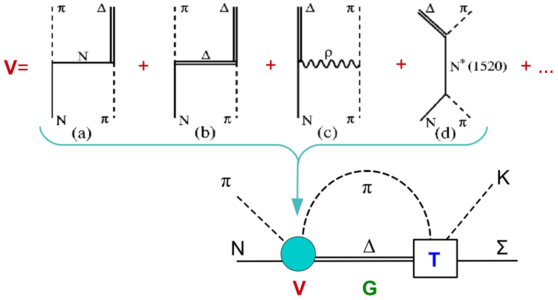
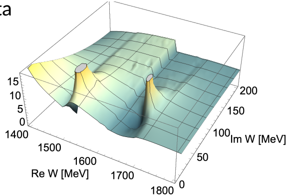


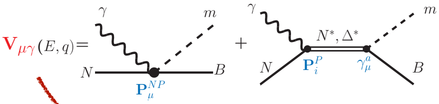
- potentials V constructed from effective $\mathcal{L}$
- constraints from unitarity, analyticity, chiral symmetry
- dynamical generation of poles possible
- free parameters fitted to data

- resonances = **poles** on the unphysical Riemann sheet of T

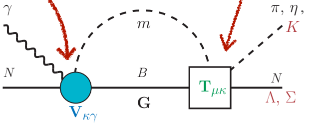


Photoproduction reactions in a semi-phenomenological approach

EPJ A 50, 101 (2014)



hadronic rescattering process

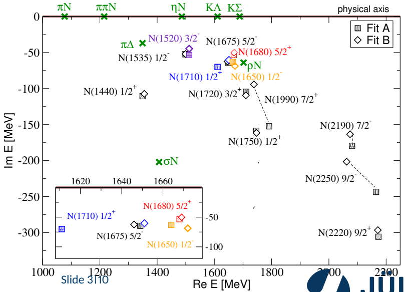


$$V_{\mu\gamma}(E,q) = \frac{\tilde{\gamma}^a_\mu(q)}{m_N} P^{\rm NP}_\mu(E) + \sum_i \frac{\gamma^a_{\mu;i}(q) P^{\rm P}_i(E)}{E - m^b_i}$$

$P^{\rm NP}_\mu$, $P^{\rm P}_i$: energy dependent polynomials

Constraints from pion-induced reactions!

→ fit pion- & photon-induced reactions simultaneously ($>$ 1000 free parameters) → full resonances spectrum



Photoproduction off neutron targets (preliminary)

Simultaneous fit of $\gamma n \to \pi^- p$, $\pi^+ n$ and $\gamma p \to X$ and $\pi N \to X$ ($X = \pi N, \eta N, K\Lambda, K\Sigma$) $\to$ 89k data points

Challenge from existing data:

- very few data at low energy $\to$ difficult to constrain the amplitude $\to$ $nM^{1/2}$ less well determined

  $\to$ large effects e.g. on predictions of GHD sum rule $I_{GDH} = \frac{2\pi^2\alpha}{M^2}\kappa^2 = \int_{E_\gamma^{thr}}^{\infty} \frac{\Delta\sigma}{E_\gamma}\, \mathrm{d}E_\gamma$ $\left(I_{GDH}(E_\gamma) = \int_{E_\gamma^{thr}}^{E_\gamma} \frac{\Delta\sigma(E'_\gamma)}{E'_\gamma}\, \mathrm{d}E'_\gamma \right)$

- running GDH integral at $E_\gamma = 2.5$ GeV

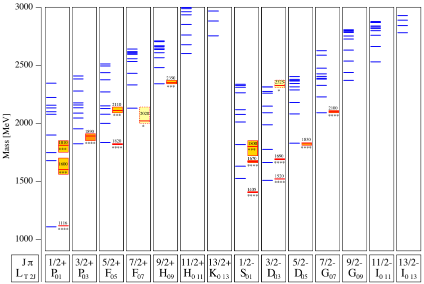
proton target	JüBo 2025 EPJ A 61 (2025)	SAID PRC 105 (2022)
$I^p_{GDH}(\pi^0 p)$	147 ± 7	155
$I^p_{GDH}(\pi^+ n)$	29 ± 15	30

neutron target	JüBo 2026 prelim. Schneider et al.	SAID PRC 105 (2022)
$I^n_{GDH}(\pi^0 n)$	118	150
$I^n_{GDH}(\pi^- p)$	77	-20

(all numbers in μb)

The Hyperon Spectrum (Λ^*'s and Σ^*'s)

Relativistic quark model: Λ^*'s



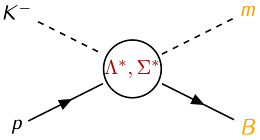
Löring *et al.* EPJ A 10, 447 (2001), Model A, exp. spectrum: PDG 2000

- Testing ground for theories of the strong force: what happens if we replace a light quark with an s quark?
- even more missing resonances than for N^*'s and Δ^*'s
- high interest in low-energy region and $\Lambda(1405)$ Review: Mai, Eur.Phys.J.ST 230 (2021)
- very little new experimental data in the last decades for the complete resonance region

Review on Hyperon spectroscopy:

E. Klempt et al. Eur.Phys.J.A 56 (2020)

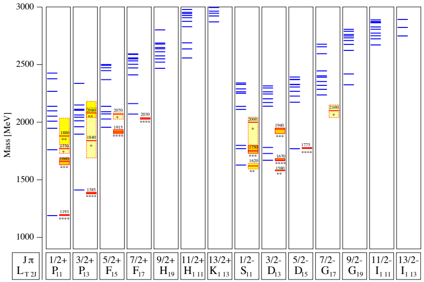
$K^- p$ scattering



Photoproduction

The Hyperon Spectrum (Λ^*'s and Σ^*'s)

Relativistic quark model: Σ^*'s



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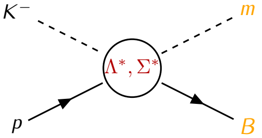
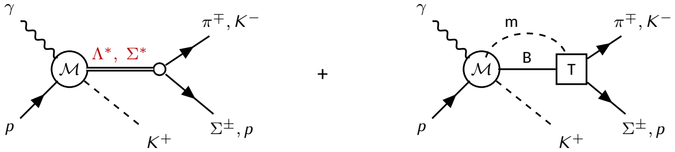


Photoproduction



The Hyperon Spectrum

4 groups re-analyzed old $K^- p$ data over the complete resonance region:

- Kent: multi-channel PWA of $\bar{K}N$ scattering, $W = 1480$ to 2100 MeV PRC 88, 035204 & PRC 88, 035205 (2013)
- JPAC: unitary multichannel model for $\bar{K}N$ scattering, fit to Kent SE PWA PRD 93, 034029 (2016)
- **ANL/Osaka**: dynamical coupled-channel model for $\bar{K}N$ reactions PRC 90, 065204 (2014) & PRC 92, 025205 (2015)
- **BnGa**: multi-channel PWA based on a modified K-matrix approach EPJA 55,179 & 180 (2019)

- JüBo: publication in preparation!

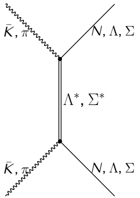
Same DCC eq. as for πN reactions:

$$\langle L'S'p'|T_{\mu\nu}|LSp\rangle = \langle L'S'p'|V_{\mu\nu}|LSp\rangle + \sum_{\kappa,L''S''}\int_0^\infty dq \quad q^2 \quad \langle L'S'p'|V_{\mu\kappa}|L''S''q\rangle \frac{1}{E - E_\kappa(q) + i\epsilon}\langle L''S''q|T_{\kappa\nu}|LSp\rangle$$

- From πN to $\bar{K}N$ using SU(3) flavor symmetry in $V^{\rm NP}$
- So far: μ, ν, κ=$\bar{K}N, \pi\Lambda, \pi\Sigma$

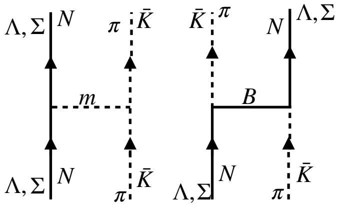
JüBo $\bar{K}N$ model: free parameter

s-channel: resonances (T^P)



- 10 $I = 0$ s-channel poles: m^b, $f_b^{\bar{K}N}$, $f_b^{\pi\Sigma}$ each
- 12 $I = 1$ s-channel poles: m^b, $f_b^{\bar{K}N}$, $f_b^{\pi\Lambda}$, $f_b^{\pi\Sigma}$ each
  $\rightarrow$ 80 fit parameters
- phenomenological ct terms in some PWs
  $\rightarrow$ 31 fit parameters

t- and u-channel exchange: "background" (T^{NP})



cut offs Λ in form factors $\left(\frac{\Lambda^2 - m_{ex}^2}{\Lambda^2 + \vec{q}^2}\right)^n$ (couplings fixed from SU(3))

	$\pi\Lambda$	$\pi\Sigma$	$\bar{K}N$
$\pi\Lambda$	f_0, Σ, Σ^*	ρ, Σ, Σ^*	N, K^*, K_0^*
$\pi\Sigma$	ρ, Σ, Σ^*	$\Lambda, \Sigma, \Sigma^*, f_0, \rho$	N, Δ, K_0^*, K^*
$\bar{K}N$	N, K^*, K_0^*	N, Δ, K_0^*, K^*	ρ, ω, f_0, a_0

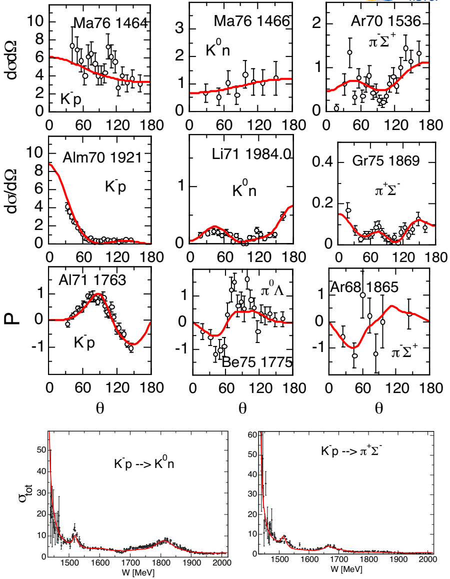
$\rightarrow$ 31 fit parameters

$\rightarrow$ 142 fit parameters in total

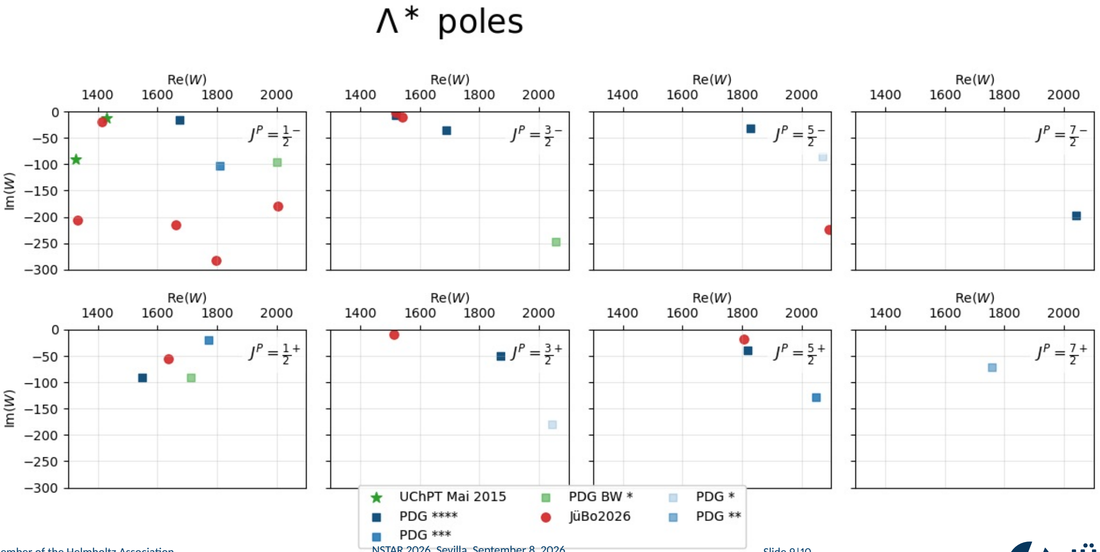
JüBo $\bar{K}N$ model: Data base ($W \leq 2$ GeV)

$K^- p \to$	Observable (# of data p.)	$K^- p \to$	Observable (# of data p.)
$K^- p$	$d\sigma/d\Omega$ (4545)	$\pi^-\Sigma^+$	$d\sigma/d\Omega$ (1882)
	P (898)		P (578)
	σ_{tot} (178)		σ_{tot} (196)
total # data p. $K^- p$: 5621		total # data p. $\pi^-\Sigma^+$: 2816	
$K^0 n$	$d\sigma/d\Omega$ (3210)	$\pi^0\Sigma^0$	$d\sigma/d\Omega$ (581)
			P (124)
			$P \times d\sigma/d\Omega$ (190)
	σ_{tot} (238)		σ_{tot} (126)
total # data p. $K^0 n$: 3448		total # data p. $\pi^0\Sigma^0$: 1021	
$\pi^0\Lambda$	$d\sigma/d\Omega$ (2132)	$\pi^+\Sigma^-$	$d\sigma/d\Omega$ (1881)
	P (660)		
	$P \times d\sigma/d\Omega$ (190)		
	σ_{tot} (196)		σ_{tot} (171)
total # data p. $\pi^0\Lambda$: 3178		total # data p. $\pi^+\Sigma^-$: 2052	
SIDDHARTA	scattering length (2)	2	

total number of data p.: 18138



JüBo $\bar{K}N$ model: resonance spectrum (preliminary)



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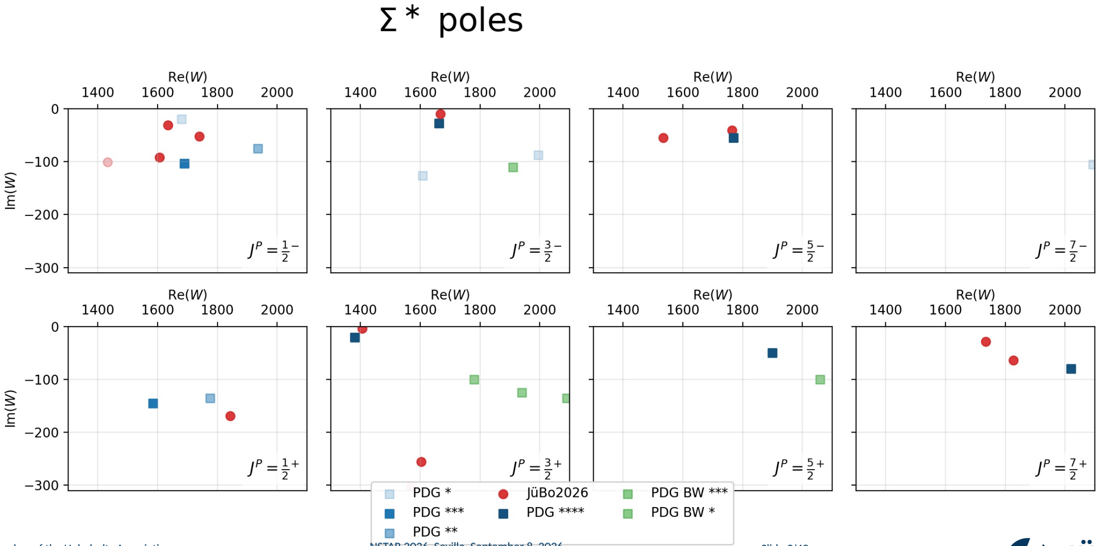

Summary and Outlook

JüBo DCC analysis extended to include photoproduction off neutron targets

- analysis of $\gamma n \to \pi^- p, \pi^+ n$ simultaneous with $\gamma p \to X$ and $\pi N \to X$ ($X = \pi N, \eta N, K\Lambda, K\Sigma$)
- determination of neutron photo couplings and GHD sum rule (preliminary)
- updated N^* and Δ^* spectrum (preliminary)

JüBo DCC for Hyperon spectrum

- adaptation of πN JüBo model using $SU(3)$ symmetry
- simultaneous analysis of $K^- p \to K^- p, \pi\Lambda, \pi\Sigma$
- fit to $\sim$ 18,000 data points ($d\sigma/d\Omega$, P, σ_{tot}, $K^- p$ scattering length)
- determination of Λ^* and Σ^* spectrum (publication in preparation)
- prospects for new data from different facilities (INSIGHT@ELSA, KLF, ...)

Thank you for your attention!

Photoproduction off neutron targets (preliminary)

Simultaneous fit of $\gamma n \to \pi^- p$, $\pi^+ n$ and $\gamma p \to X$ and $\pi N \to X$ ($X = \pi N, \eta N, K\Lambda, K\Sigma$) $\to$ 89k data points

proton vs. neutron target: same photon couplings for Δ^*'s, different photon coupling for N^*'s!

Challenge from existing data:

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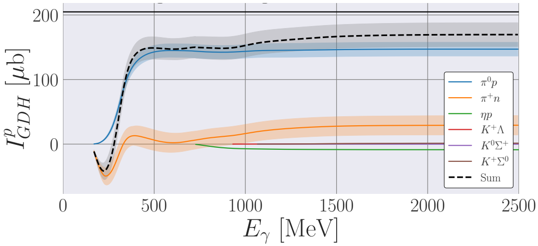
  $\to$ large effects e.g. on predictions of GHD sum rule $I_{GDH} = \frac{2\pi^2\alpha}{M^2}\kappa^2 = \int_{E_\gamma^{thr}}^{\infty} \frac{\Delta\sigma}{E_\gamma}\,\mathrm{d}E_\gamma$ ($I_{GDH}(E_\gamma) = \int_{E_\gamma^{thr}}^{E_\gamma} \frac{\Delta\sigma(E'_\gamma)}{E'_\gamma}\,\mathrm{d}E'_\gamma$)

- running GDH integral at $E_\gamma = 2.5$ GeV

Proton target:



JüBo 2025 Schneider et al. EPJ A 61 (2025)

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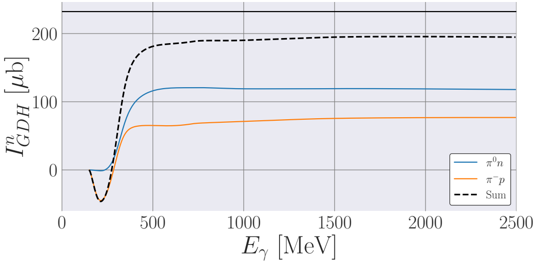
- running GDH integral at $E_\gamma = 2.5$ GeV

Neutron target:



JüBo 2026 prelim. Schneider et al. preliminary

Photoproduction off neutron targets

JüBo extension in progress (C. Schneider)

- Isospin formalism for photoproduction: $pT^{1/2}$, $nT^{1/2}$, $T^{3/2}$ (same for proton/neutron target)

  $\rightarrow$ same photon coupling for Δ's

  $\rightarrow$ different photon coupling for N^*'s! (but pole positions are universal!)
- $nT^{1/2}$ much less well determined
- potential for discovery of new N^*'s

Challenge from existing data:

- much less in general than for proton photoproduction
- very few at low energy
  $\rightarrow$ difficult to constrain the amplitude
  $\rightarrow$ large effects e.g. on predictions of GHD sum rule

New data from INSIGHT@ELSA

- JüBo will be ready to analyze the data
- prerequisite to claim existence of new states: good statistics and polarization data

$\rightarrow$ refine the N^* and Δ spectrum

PDG Λ^* ratings 1984 (left) vs 2026 (right)

Particle	$L_{I\cdot 2J}$	Overall status	Status as seen in -- $N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	P_{01}	****				$N\pi$ (weakly)
$\Lambda(1405)$	S_{01}	****	****	F	****	
$\Lambda(1520)$	D_{03}	****	****	o	****	$\Lambda\pi\pi$, $\Lambda\gamma$
$\Lambda(1600)$	P_{01}	***	***	r	**	
$\Lambda(1670)$	S_{01}	****	****	b	****	$\Lambda\eta$
$\Lambda(1690)$	D_{03}	****	****	i	****	$\Lambda\pi\pi$, $\Sigma\pi\pi$
$\Lambda(1800)$	S_{01}	***	***	d	**	$N\bar{K}^*$, $\Sigma(1385)\pi$
$\Lambda(1800)$	P_{01}	***	***	d	**	$N\bar{K}^*$
$\Lambda(1820)$	F_{05}	****	****	e	****	$\Sigma(1385)\,\pi$
$\Lambda(1830)$	D_{05}	****	***	n	****	$\Sigma(1385)\,\pi$
$\Lambda(1890)$	P_{03}	****	****	F	**	$N\bar{K}^*$, $\Sigma(1385)\pi$
$\Lambda(2000)$		*		o	*	$\Lambda\omega$, $N\bar{K}^*$
$\Lambda(2020)$	F_{07}	*	*	r	*	
$\Lambda(2100)$	G_{07}	****	****	b	***	$\Lambda\omega$, $N\bar{K}^*$
$\Lambda(2110)$	F_{05}	***	**	i	*	$\Lambda\omega$, $N\bar{K}^*$
$\Lambda(2325)$	D_{03}	*	*	d		$\Lambda\omega$
$\Lambda(2350)$		***	***	d	*	
$\Lambda(2585)$		**	**	e		
				n		

C. G. Wohl *et al.* (Particle Data Group) Rev.Mod. Phys. 56 (1984)

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

R. L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

Status updated   Quantum numbers updated   New

PDG Σ^* ratings 1984 (left) vs 2026 (right)

color meets flavor

Particle	$L_{I\cdot 2J}$	Overall status	$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
			Status as seen in --			
Σ(1193)	P_{11}	****				$N\pi$ (weakly)
Σ(1385)	P_{13}	****		****	****	
Σ(1480)		*	*	*	*	
Σ(1560)		**		**	**	
Σ(1580)	D_{13}	**	*	*		
Σ(1620)	S_{11}	**	**	*	*	
Σ(1660)	P_{11}	***	***	*	**	
Σ(1670)	D_{13}	****	****	****	****	several others
Σ(1690)		**	*	**	*	$\Lambda\pi\pi$
Σ(1750)	S_{11}	***	***	**	*	$\Sigma\eta$
Σ(1770)	P_{11}	*				
Σ(1775)	D_{15}	****	****	****	***	several others
Σ(1840)	P_{13}	*	*	**	*	
Σ(1880)	P_{11}	**	**	**		$N\bar{K}^*$
Σ(1915)	F_{15}	****	***	****	***	$\Sigma(1385)\pi$
Σ(1940)	D_{13}	***	*	***	**	quasi-2-body
Σ(2000)	S_{11}	*		*		$N\bar{K}^*$, $\Lambda(1520)\pi$
Σ(2030)	F_{17}	****	****	****	**	several others
Σ(2070)	F_{15}	*	*		*	
Σ(2080)	P_{13}	**		**		
Σ(2100)	G_{17}	*		*	*	
Σ(2250)		***	***	*	*	
Σ(2455)		**	*			
Σ(2620)		**	*			
Σ(3000)		*	*	*		
Σ(3170)		*				multi-body

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

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Status updated | Quantum numbers updated | New | Removed