The spectrum of hyperon resonances from a partial wave analysis of K-p scattering data

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Contents

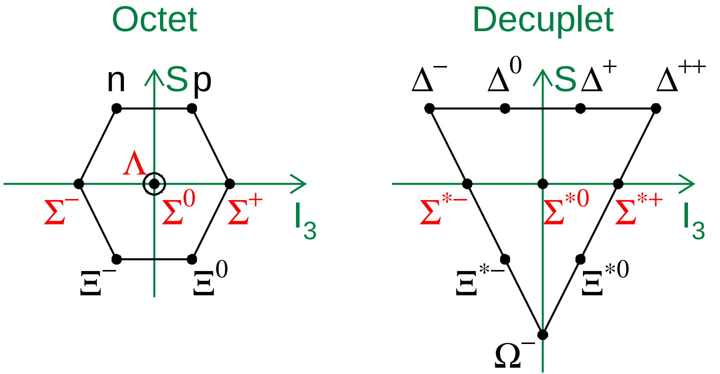
Quark model

The flavour and spin can be combined in spin-flavour SU(6):

$$6 \otimes 6 \otimes 6 = 56_S \oplus 70_M \oplus 70_M \oplus 20_A$$

where

$$56 = {}^4 10 \oplus {}^2 8$$
$$70 = {}^2 10 \oplus {}^4 8 \oplus {}^2 8 \oplus {}^2 1$$
$$20 = {}^2 8 \oplus {}^4 1$$



Quark model classification. Ground and 1st excitation shell

two states on ground shell
2 Λ as singlets 6 Λ and 6 Σ states as octet members on a 1st shell

(D, L_N^P)	S	J^P	Octet members			Singlets
$(56, 0_0^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(939)$	$\Lambda(1116)^{4*}$	$\Sigma(1193)^{4*}$	-
$(70, 1_1^-)$	$\frac{1}{2}$	$\frac{1}{2}^-$	$N(1535)$	$\Lambda(1670)^{4*}$	$\Sigma(1620)^{2*}$	$\Lambda(1405)^{4*}$
		$\frac{3}{2}^-$	$N(1520)$	$\Lambda(1690)^{4*}$	$\Sigma(1670)^{4*}$	$\Lambda(1520)^{4*}$
	$\frac{3}{2}$	$\frac{1}{2}^-$	$N(1650)$	$\Lambda(1800)^{3*}$	$\Sigma(1750)^{3*}$	-
		$\frac{3}{2}^-$	$N(1700)$			-
		$\frac{5}{2}^-$	$N(1675)$	$\Lambda(1830)^{4*}$	$\Sigma(1775)^{4*}$	-

3 Σ states are expected as decuplet members

(D, L_N^P)	S	J^P	Decuplet members	
$(56, 0_0^+)$	$\frac{3}{2}$	$\frac{3}{2}^+$	$\Delta(1232)$	$\Sigma(1385)^{4*}$
$(70, 1_1^-)$	$\frac{1}{2}$	$\frac{1}{2}^-$	$\Delta(1620)$	
	$\frac{1}{2}$	$\frac{3}{2}^-$	$\Delta(1700)$	

Quark model classification. 2nd excitation shell

(D, L_N^P)	S	J^P	Octet members			Singlets
$(56, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1440)$	$\Lambda(1600)^{3*}$	$\Sigma(1660)^{3*}$	-
$(70, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1710)$	$\Lambda(1810)^{3*}$	$\Sigma(1770)^{1*}$	-
$(56, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$N(1720)$	$\Lambda(1890)^{4*}$	$\Sigma(1840)^{1*}$	-
		$\frac{5}{2}^+$	$N(1620)$	$\Lambda(1820)^{4*}$	$\Sigma(1915)^{4*}$	-
$(70, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$N(1900)$			-
		$\frac{5}{2}^+$	$N(1860)$			-
	$\frac{3}{2}$	$\frac{1}{2}^+$	$N(1880)$			-
		$\frac{3}{2}^+$	$N(1960)$		$\Sigma(2080)^{2*}$	-
		$\frac{5}{2}^+$	$N(2000)$	$\Lambda(2110)^{3*}$	$\Sigma(2070)^{1*}$	-
		$\frac{7}{2}^+$	$N(1990)$	$\Lambda(2020)^{1*}$	$\Sigma(2030)^{4*}$	-
$(20, 1_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(2100)$			-
		$\frac{3}{2}^+$	$N(2040)$		$\Sigma(2080)^{2*}$	-

Motivation

1. There are a lot missing states in hyperon spectrum in comparison with N and Δ spectrum in frame of quark model classification
2. The investigation of hyperon spectrum expands understanding of baryon properties and their classification.
3. BnGa approach allow to include near all experimental data in combine analysis, specially to include reaction with three-particle final states

Scattering amplitude in BnGa approach

1. Energy dependent approach
2. Possibility to combine all data in one analysis
3. K-matrix satisfies unitarity condition

$$A(s,t) = \sum_{IJN} C_I Q_{JN}(s,t) A_{IJN}(s)\,,$$

1. C_I are the Clebsch-Gordan coefficients
2. Q_{JN} tensors describe the angular dependent part of the partial wave amplitudes.
3. $A_{IJN}(s)$ are partial wave amplitudes (Breit-Wigner function and K-Matrix)

Non-resonance contributions are described by constants in the K-matrix and by amplitudes for t and u-channel exchanges

Data base of K^-p reactions

Total mass range: (1.46 - 2.3) GeV

Differential cross sections $d\sigma/d\Omega$ (16316 points)

$K^-p \to K^-p$	(12, 5170)	$K^-p \to K^0 n$	(11, 3445)
$K^-p \to \pi^0\Lambda$	(11, 2478)	$K^-p \to \eta\Lambda$	(2, 160)
$K^-p \to \pi^0\Sigma^0$	(5, 581)	$K^-p \to \pi^\mp\Sigma^\pm$	(8, 4177)
$K^-p \to K^{-}_{0}\,\Xi^{+}_{0}$	(5, 305)		

Data on the polarization observable P (2818 points)

$K^-p \to K^0 n$	(5, 1180)	$K^-p \to \pi^0\Lambda$	(7, 892)
$K^-p \to \pi^0\Sigma^0$	(1, 124)	$K^-p \to \pi^-\Sigma^+$	(5, 593)
$K^-p \to K^{-}_{0}\,\Xi^{+}_{0}$	(1, 29)		

Data three-body final states (3711 points)

$K^-p \to \omega\Lambda$	(3, 300)	$K^-p \to \bar{K}\Delta(1232)$	(2, 667)
$K^-p \to \pi^\mp\Sigma^\pm(1385)$	(2, 899)	$K^-p \to \pi^0\Lambda(1520)$	(4, 1011)
$K^-p \to K^{*0}n$	(2, 371)	$K^-p \to K^{*-}p$	(2, 463)

Data event-by-event in an event-based likelihood fit

$K^-p \to 2\pi^0\Lambda$	(1, 26513)	$K^-p \to 2\pi^0\Sigma$	(1, 3286)

Step 1: Hyperon set for the primary fit.

	J^P	Status	Mass	Width
$\Lambda(1405)$	$1/2^-$	****	$1405^{+1.3}_{-1.0}$	50.5 ± 2.0
$\Lambda(1670)$	$1/2^-$	****	$1660 - 1680$	$25 - 50$
$\Lambda(1800)$	$1/2^-$	***	$1720 - 1850$	$200 - 400$
$\Lambda(1520)$	$3/2^-$	****	1519.5 ± 1.0	15.6 ± 1.0
$\Lambda(1690)$	$3/2^-$	****	$1685 - 1695$	$50 - 70$
$\Lambda(1830)$	$5/2^-$	****	$1810 - 1830$	$60 - 110$
$\Lambda(2100)$	$7/2^-$	****	$2090 - 2110$	$100 - 250$
$\Lambda(1600)$	$1/2^+$	***	$1560 - 1700$	$50 - 250$
$\Lambda(1810)$	$1/2^+$	***	$1750 - 1850$	$50 - 250$
$\Lambda(1890)$	$3/2^+$	****	$1850 - 1910$	$60 - 200$
$\Lambda(1820)$	$5/2^+$	****	$1815 - 1825$	$70 - 90$
$\Lambda(2110)$	$5/2^+$	***	$2090 - 2140$	$150 - 250$

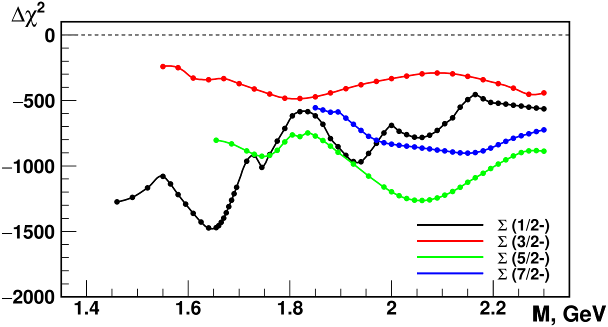
	J^P	Status	Mass	Width
$\Sigma(1750)$	$1/2^-$	***	$1730 - 1800$	$60 - 160$
$\Sigma(1670)$	$3/2^-$	****	$1665 - 1685$	$40 - 80$
$\Sigma(1940)$	$3/2^-$	***	$1900 - 1950$	$150 - 300$
$\Sigma(1775)$	$5/2^-$	****	$1770 - 1780$	$105 - 135$
$\Sigma(1660)$	$1/2^+$	***	$1630 - 1690$	$40 - 200$
$\Sigma(1385)$	$3/2^+$	****	1382.80 ± 0.35	36.0 ± 0.7
$\Sigma(1915)$	$5/2^+$	****	$1900 - 1935$	$80 - 160$
$\Sigma(2030)$	$7/2^+$	****	$2025 - 2040$	$150 - 200$

Primary Briet-Wigner fit includes set of hyperons with 4 and 3 stars RPP rating only

Masses and widths are allowed to vary within the limits quoted in the RPP

Step 2: Mass scan procedure

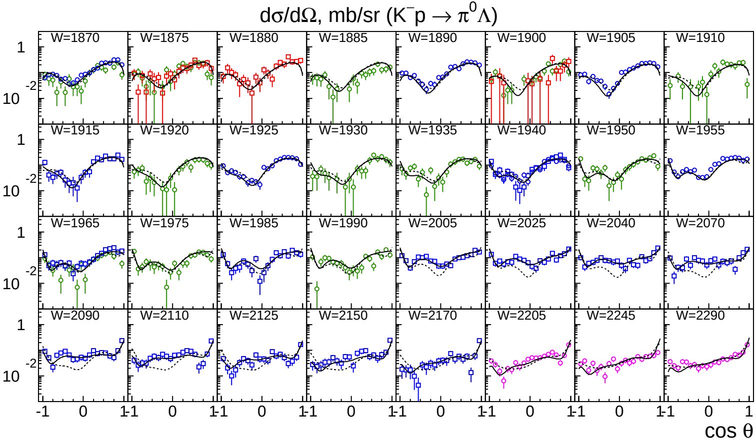
- to take a primary solution with well establish states
- to add resonance with fix mass to partial wave and to fit
- to repeat it for whole investigated mass region and all partial waves



$J^P = 1/2^-$
$J^P = 3/2^-$
$J^P = 5/2^-$
$J^P = 7/2^-$

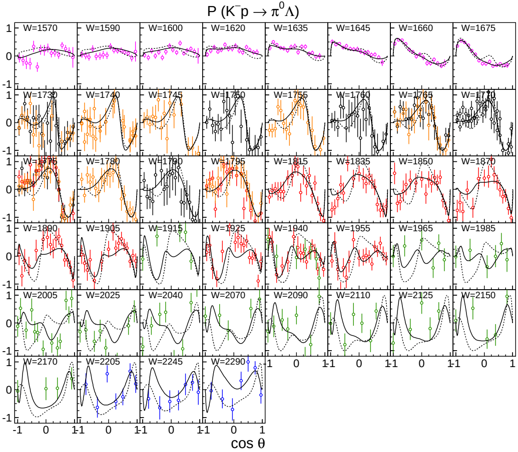
- to establish state which gives essential fit improving
- to repeat mass scan for all partial waves with this additional state
- to continue this procedure up to not significant data description improvement - mass scans are flat

Differential cross section for $K^- p \to \pi^0 \Lambda$



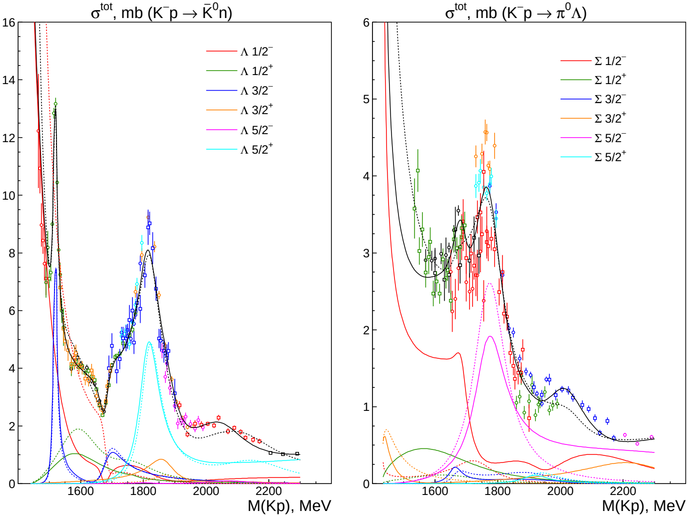
dashed line - primary fit with set of well established hyperons
solid line - final fit

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



dashed line - primary fit with set of well established hyperons
solid line - final fit

Total cross section for $K^- p \to \bar{K} n$ and $K^- p \to \pi^0 \Lambda$



dashed line - primary fit with set of well established hyperons
solid line - final fit

χ^2 difference between primary and final fits

Differential cross sections

$K^-p \to K^-p$	(2.203, 1.802)	$K^-p \to K^0 n$	(1.997, 1.545)
$K^-p \to \pi^0\Lambda$	(2.135, 1.658)	$K^-p \to \eta\Lambda$	(2.756, 1.500)
$K^-p \to \pi^0\Sigma^0$	(2.169, 1.960)	$K^-p \to \pi^\mp\Sigma^\pm$	(5.196, 4.190)
$K^-p \to K^{-}_{0}\,\Xi^{+}_{0}$	(3.052, 2.549)		

Data on the polarization observable P

$K^-p \to K^0 n$	(1.867, 1.406)	$K^-p \to \pi^0\Lambda$	(1.901, 1.244)
$K^-p \to \pi^0\Sigma^0$	(4.613, 2.411)	$K^-p \to \pi^-\Sigma^+$	(2.165, 2.094)
$K^-p \to K^{-}_{0}\,\Xi^{+}_{0}$	(2.955, 2.650)		

Data on the K^-p induced reactions with three-body final states

$K^-p \to 2\pi^0\Lambda$	$(\delta\chi^2 = -244^a)$	$K^-p \to 2\pi^0\Sigma$	$(\delta\chi^2 = -498^a)$
$K^-p \to \omega\Lambda$	(1.497, 1.027)	$K^-p \to \bar{K}\Delta(1232)$	(1.568, 1.301)
$K^-p \to \pi^\mp\Sigma^\pm(1385)3/2^+$	(3.600, 2.406)	$K^-p \to \pi^0\Lambda(1520)3/2^-$	(2.704, 1.390)
$K^-p \to K^{*0}n$	(2.776, 2.647)	$K^-p \to K^{*-}p$	(2.218, 1.948)

The spectrum of Λ hyperons with negative parity

	Mass	Width	$\Delta\chi^2$	Status
$\Lambda(1405)1/2^-$	1420±3 $1405.1^{+1.3}_{-1.0}$	46±4 50.5±2.0	4070	**** ****
$\Lambda(1670)1/2^-$	1677±2 1660 to 1680	33±4 25 to 50	3610	**** ****
$\Lambda(1800)1/2^-$	1811±10 1720 to 1850	209±18 200 to 400	1896	*** ***
$\Lambda(2000)1/2^-$	2085±14 ≈2060	428±16 100 to 300	845	* *
$\Lambda(1520)3/2^-$	1518.5±0.5 1519.5±1.0	15.7±1.0 15.6±1.0	>10 000	**** ****
$\Lambda(1690)3/2^-$	1689±3 1685 to 1695	75±5 50 to 70	>10 000	**** ****
$\Lambda(1830)5/2^-$	1821±3 1810 to 1830	64±7 60 to 110	1790	*** ****
$\Lambda(2080)5/2^-$	2082±13 -	181±29 -	770	** new
$\Lambda(2100)7/2^-$	2090±15 2090 to 2110	290±30 100 to 250	5412	**** ****

The spectrum of Λ hyperons with positive parity

	Mass	Width	$\Delta\chi^2$	Status
$\Lambda(1600)1/2^+$	1605±8 1560 to 1700	245±15 50 to 250	>10 000	**** ***
$\Lambda(1810)1/2^+$	1773±5 1750 to 1850	36±6 50 to 250	46	* ***
$\Lambda(1890)3/2^+$	1873±5 1850 to 1910	103±10 60 to 200	4480	**** ****
$\Lambda(2070)3/2^+$	2070±24 -	370±50 -	1144	** new
$\Lambda(1820)5/2^+$	1822±4 1815 to 1825	80±8 70 to 90	>10 000	**** ****
$\Lambda(2110)5/2^+$	2086±12 2090 to 2140	274±25 150 to 250	1418	** ***

The spectrum of Σ hyperons with negative parity

	Mass	Width	$\Delta\chi^2$	Status
$\Sigma(1620)1/2^-$	1681±6 ≈1620	40±12 10 to 400	386	* *
$\Sigma(1750)1/2^-$	1692±11 1730 to 1800	208±18 60 to 160	3032	**** ***
$\Sigma(1900)1/2^-$	1938±12 1900±21	155±30 191±47	1500	*** *
$\Sigma(2000)1/2^-$	2165±23 ≈2000	320^{+300}_{-60} 100 to 400	1612	** *
$\Sigma(1670)3/2^-$	1665±3 1665 to 1685	54±6 40 to 80	5894	**** ****
$\Sigma(1860)3/2^-$	1878±12 -	224±25 -	1708	*** new
$\Sigma(1940)3/2^-$	2005±14 1900 to 1950	178±23 150 to 300	446	* ***
$\Sigma(1775)5/2^-$	1776±4 1770 to 1780	124±8 105 to 135	>10 000	**** ****
$\Sigma(2100)7/2^-$	2146±17 ≈2100	260±40 50 to 150	668	* *

The spectrum of Σ hyperons with positive parity

	Mass	Width	$\Delta\chi^2$	Status
$\Sigma(1660)1/2^+$	1665±20 1630 to 1690	300^{+140}_{-40} 40 to 200	1870	**** ***
$\Sigma(1385)3/2^+$	1385 1383.7± 1.0	36 36±5		**** ****
$\Sigma(2230)3/2^+$	2240±27	345±50	1200	** new
$\Sigma(1915)5/2^+$	1918±6 1900 to 1935	102±12 80 to 160	2002	**** ****
$\Sigma(2030)7/2^+$	2032±6 2025 to 2040	177±12 150 to 200	2856	**** ****

Non established RPP states

In the mass range below 2200 MeV, we find no any evidence for:

1. three "bumps": $\Sigma(1480)$, $\Sigma(1670)$, and $\Sigma(1690)$,
2. eight states with 1*: $\Lambda(1710)1/2^+$, $\Lambda(2020)7/2^+$, $\Lambda(2050)3/2^-$ $\Sigma(1580)3/2^-$, $\Sigma(1730)3/2^+$, $\Sigma(1770)1/2^+$, $\Sigma(1940)3/2^+$, $\Sigma(2070)5/2^+$
3. three states with 2*: $\Sigma(1560)$, $\Sigma(1880)1/2^+$, $\Sigma(2080)3/2^+$.

Comparison with the Bonn quark model: Λ sector

Λ^* resonances						
J^π	RPP	BnGa	M_{QM}	$^2 1[70]$	$^2 8[70]$	$^4 8[70]$
$\frac{1}{2}^-$	$1405.1^{+1.3}_{-1.0}$	1422 ± 3	1524	$\underline{69.4}$	26.0	0.3
$\frac{3}{2}^-$	1519.5 ± 1.0	1518.5 ± 0.5	1508	$\underline{77.7}$	18.7	0.1
$\frac{1}{2}^-$	1670 ± 10	1677 ± 2	1630	29.2	$\underline{61.6}$	2.1
$\frac{3}{2}^-$	1690 ± 5	1689 ± 3	1662	20.1	$\underline{72.0}$	2.2
$\frac{1}{2}^-$	1800^{+50}_{-80}	1811 ± 10	1816	0.1	3.1	$\underline{94.9}$
$\frac{3}{2}^-$	-	-	1775	0.4	1.5	$\underline{96.1}$
$\frac{5}{2}^-$	$1830^{+\ 0}_{-20}$	1821 ± 3	1828	0.0	0.0	$\underline{99.0}$
$\frac{5}{2}^-$	–	2082 ± 13	2080	large		
$\frac{7}{2}^-$	2100 ± 10	2090 ± 15	2090	large		
J^π	RPP	BnGa	M_{QM}	$^2 1[70]$	$^2 8[56]$	$^2 8[70]$
$\frac{1}{2}^+$	1600^{+100}_{-40}	1605 ± 8	1677	0.3	$\underline{88.4}$	3.0
$\frac{1}{2}^+$	1810^{+40}_{-60}	1773 ± 7	$\underline{90\%}$ $^2[70]$ 1747 or $\underline{84\%}$ $^2 8[70]$ 1898			
$\frac{3}{2}^+$	1890^{+20}_{-40}	1872 ± 5	1823	9.9	$\underline{60.0}$	28.2
$\frac{5}{2}^+$	1820 ± 5	1822 ± 4	1834	28.3	$\underline{57.8}$	12.2
$\frac{3}{2}^+$	-	2070 ± 24	1952	$\underline{84.0}$	3.8	7.6
$\frac{5}{2}^+$	2110^{+30}_{-20}	2086 ± 12	1999	$\underline{84.1}$	4.5	8.9

Comparison with the Bonn quark model: Σ sector

Σ^* resonances						
J^π	RPP	BnGa	$M_{\rm QM}$	$^2 8[70]$	$^4 8[70]$	$^4 10[70]$
$\frac{1}{2}^-$ ~1620	1681±6	1628	87.4	2.3	3.4	
$\frac{3}{2}^-$	1670^{+15}_{-5}	1665±3	1669	89.0	1.2	3.4
$\frac{1}{2}^-$	1750^{+50}_{-20}	1692±11	1771	2.9	94.6	1.1
$\frac{3}{2}^-$	-	-	1728	0.1	82.7	16.0
$\frac{5}{2}^-$	1775 ± 5	1776±4	1770	0.0	99.0	0.0
$\frac{1}{2}^-$	~1900	1938±12	1798	2.8	1.7	94.4
$\frac{3}{2}^-$	1940^{+10}_{-40}	2005±14	1781	4.4	15.0	79.3
J^π	RPP	BnGa	$M_{\rm QM}$	$^2 8[56]$	$^4 8[70]$	$^4 10[56]$
$\frac{1}{2}^-$	-	2165±23	2111	large		
$\frac{3}{2}^-$	-	-	2139	large		
$\frac{1}{2}^+$	1660±30	1665±20	1628	87.4	2.3	5.4
$\frac{3}{2}^+$	~1840	-	1896	73.9	22.2	0.0
$\frac{5}{2}^+$	1915^{+20}_{-15}	1917±6	1956	77.8	18.2	0.0
$\frac{7}{2}^+$	2030^{+10}_{-5}	2032±6	2070		29.4	69.6
$\frac{3}{2}^+$		2240±27				

Conclusion

1. Combine fit near all available experimental data
2. 4 new resonances are proposed: $\Lambda(2080)5/2^-(**)$, $\Lambda(2070)3/2^+(**)$, $\Sigma(1860)3/2^-(***)$ and $\Sigma(2230)3/2^+(**)$
3. 5 resonances with one and two stars are seen: $\Lambda(2000)1/2^-$, $\Sigma(1620)1/2^-(*)$, $\Sigma(1900)1/2^-(***)$, $\Sigma(2000)1/2^-(*)$, $\Sigma(2100)7/2^-(*)$
4. We did not find evidence for 3 "bumps" and 11 resonances
5. Need new experimental data on K^-p scattering with polarized target.