Baryon Resonances and Strong QCD

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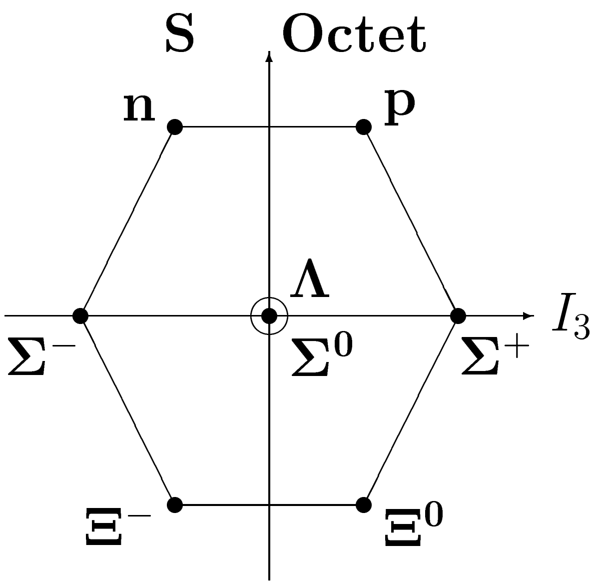
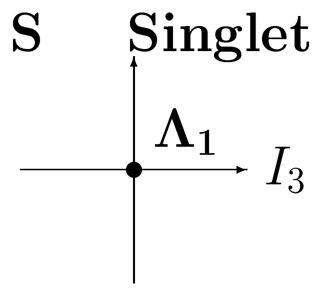
- Introduction
- Models of baryon spectroscopy
- Regge trajectories
- A mass formula for baryon resonances
- A new interpretation of strong QCD
- Conclusions

INTRODUCTION: WHY BARYON SPECTROSCOPY

Baryons have played a decicive role in the development of the quark model and of SU(3).

The octet baryons (total spin J = 1/2):





The decuplet baryons (total spin J = 3/2):

Δ^-	Δ^0	Δ^+	Δ^{++}	S = 0
Σ^-	Σ^0	Σ^+		S = - 1
Ξ^-	Ξ^0			S = - 2
Ω^-				S = - 3

Baryons (with 3 quarks): 3 flavours x 2 spins.

$$\mathbf{6} \otimes \mathbf{6} \otimes \mathbf{6} = \mathbf{56} \oplus \mathbf{70_M} \oplus \mathbf{70_M} \oplus \mathbf{20}$$

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

The 56-plet contains

N^*'s with spin 1/2
Δ^*'s with spin 3/2

The 70-plet contains

N^*'s with spin 1/2 and with spin 3/2
Δ^*'s with spin 1/2

(8_M) have a mixed flavour symmetry, the 10 multiplet is symmetric, the 1 antisymmetric in flavour space.

EXPERIMENTAL STATUS

The Particle Data Group lists:

Octet	**N**		$\boldsymbol{\Sigma}$	$\boldsymbol{\Lambda}$	$\boldsymbol{\Xi}$	
Decuplet		$\boldsymbol{\Delta}$	$\boldsymbol{\Sigma}$		$\boldsymbol{\Xi}$	$\boldsymbol{\Omega}$
Singlet				$\boldsymbol{\Lambda}$		
****	**11**	**7**	**6**	**9**	**2**	**1**
***	**3**	**3**	**4**	**5**	**4**	**1**
**	**6**	**6**	**8**	**1**	**2**	**2**
*	**2**	**6**	**8**	**3**	**3**	**0**
No J	**-**	**-**	**5**	**-**	**8**	**4**
Total	**22**	**22**	**26**	**18**	**11**	**4**

- $\sim$ **100 baryon resonances**
- $\sim$ **85 baryon resonances of known spin parity**
- $\sim$ **50 well established baryon resonances of known spin parity**

Basics of Baryon Spectroscopy

The baryon wave function:

$$|\mathbf{qqq}> = |\mathbf{colour}>_A \cdot |\mathbf{space, spin, flavour}>_S$$

$$\mathbf{O(6)} \qquad \mathbf{SU(6)}$$

The total wave function must be antisymmetric w.r.t. the exchange of any two quarks. The colour wave function is antisymmetric, hence the space-spin-flavour wave function must be symmetric. We now construct wave functions.

Spatial Symmetry

Jacobean coordinates:

$$\mathbf{r}_1 - \mathbf{r}_2$$
$$\mathbf{r}_1 + \mathbf{r}_2 - 2\mathbf{r}_3$$
$$\mathbf{r}_1 + \mathbf{r}_2 + \mathbf{r}_3$$

- **Two relevant separable motions**
- **System is bound ⇒**
- **Two harmonic oscillators**

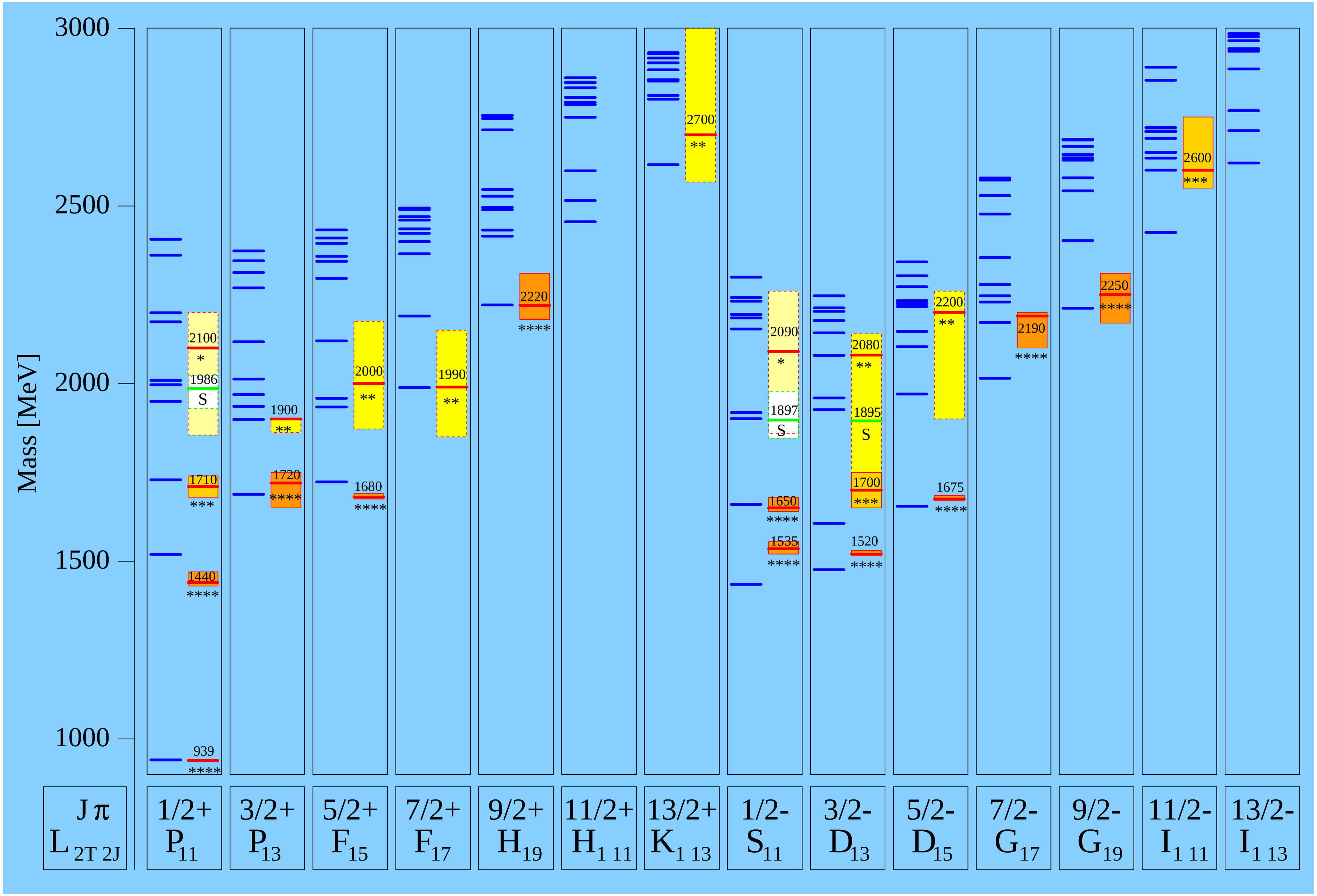
Multiplet-structure of harmonic oscillator (Hey and Kelly, Phys. Rep. 96 (1986) 71). $\mathbf{O(6) \rightarrow\ O(3) \otimes\ O(2)}$

N	O(6)	$O(3) \otimes O(2)$	(D, L^P_N)
0	1	$1 \otimes 1$	$(56, 0^+_0)$
1	6	$3 \otimes 2_1$	$(70, 1^-_1)$
2	20	$(5+1) \otimes 2_2$	$(70, 2^+_2)$, $(70, 0^+_2)$
		$5 \otimes 1$	$(56, 2^+_2)$
		$3 \otimes 1$	$(20, 1^+_2)$
	1	$1 \otimes 1$	$(56, 0^+_2)$
3	50	$(7+3) \otimes 2_3$	$(56, 3^-_3)$, $(20, 3^-_3)$, $(56, 1^-_3)$, $(20, 1^-_3)$
		$(7+5+3) \otimes 2_1$	$(70, 3^-_3)$, $(70, 2^-_3)$, $(70, 1^-_3)$
	6	$3 \otimes 2_1$	$(70, 1^-_3)$
4	105	$(9+5+1) \otimes 2_4$	$(70, 4^+_4)$, $(70, 2^+_4)$, $(70, 0^+_4)$
		$(9+7+5+3) \otimes 2_2$	$(70, 4^+_4)$, $(70, 3^+_4)$, $(70, 2^+_4)$, $(70, 1^+_4)$
		$(9+5+1) \otimes 1$	$(56, 4^+_4)$, $(56, 2^+_4)$, $(56, 0^+_4)$
		$(7+5) \otimes 1$	$(20, 3^+_4)$, $(20, 2^+_4)$
	20	$(5+1) \otimes 1$	$(70, 2^+_4)$, $(70, 0^+_4)$
		$3 \otimes 1$	$(20, 1^+_4)$
		$5 \otimes 1$	$(56, 2^+_4)$
	1	$1 \otimes 1$	$(56, 0^+_4)$

Theoretical models and results

- **Assume quarks move in an effective confinement potential generated by a very fast colour exchange between quarks (antisymmetrising the total wave function)**
- **Assume the light quarks acquire effective mass by spontanous symmetry breaking**
- **Assume residual interactions**
  - **One gluon exchange**
    relativized **quark model (Capstick and Roberts)**
    OGE fixed to HFS (N-Δ)
    $\tilde{\text{L}} \cdot \tilde{\text{S}}$ large, in contrast to data
    Set to zero
    (comp. by $\tilde{\text{L}} \cdot \tilde{\text{S}}$ from Thomas prec. ?)
  - **Goldstone (pion) exchange**
    (Gloszman and Riska)
  - **Instanton interactions**
    Relativistic quark model
    with instanton-induced forces
    (Kretschmer, Löring, Metsch, Petry)
- **Solve equation of motion (using wave functions of the harmonic oscillator)**

N* RESONANCES WITH INSTANTON INDUCED FORCES



Many problems still unsolved:

→ **Which model is right ?**

→ **Is it true that one interaction dominates ?**

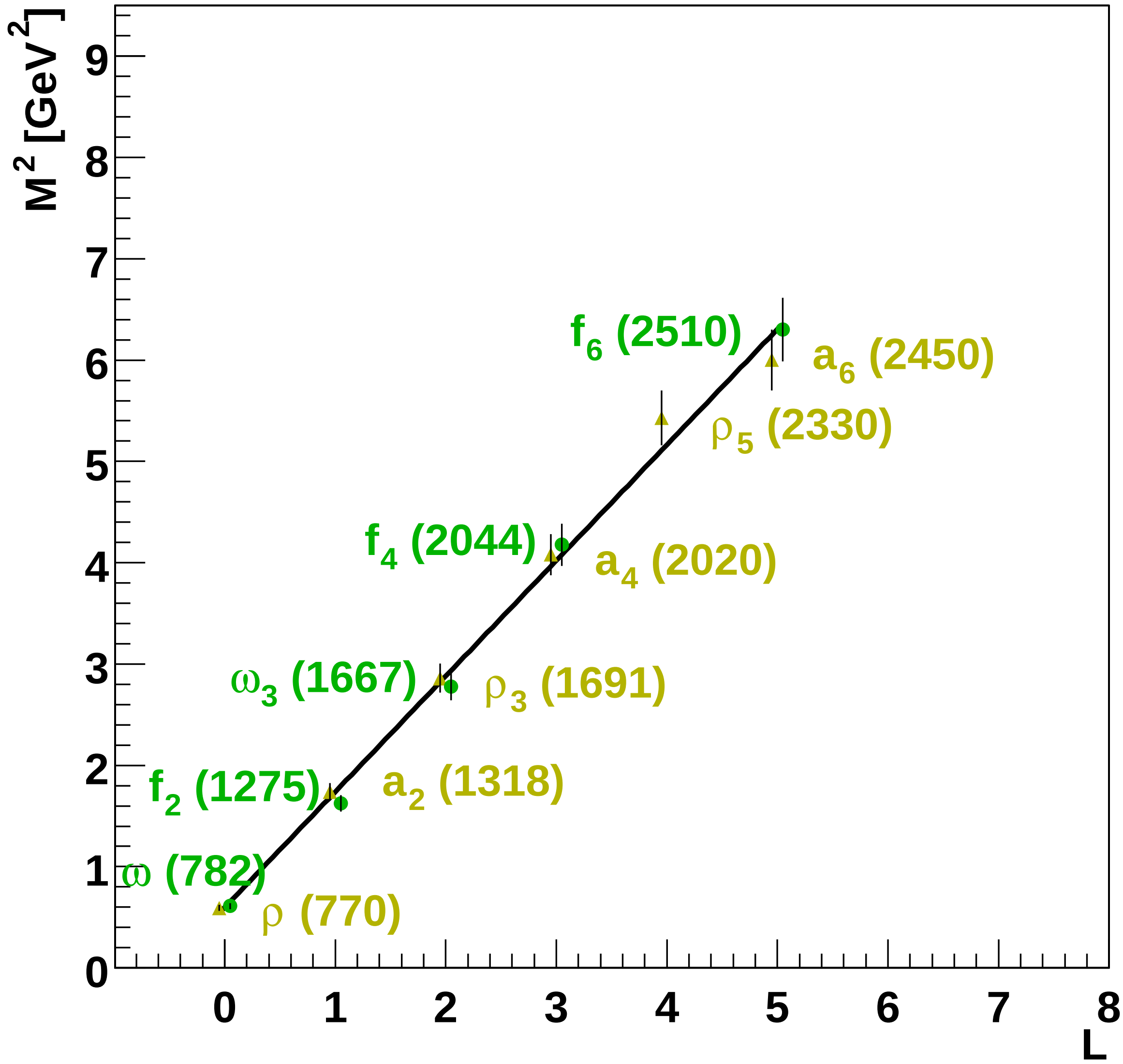
→ **Low mass of Roper, $\boldsymbol{\Delta_{3/2^+}(1600)}$ ...**

→ **Low mass of negative-parity $\boldsymbol{\Delta^*}$'s at 1950 MeV**

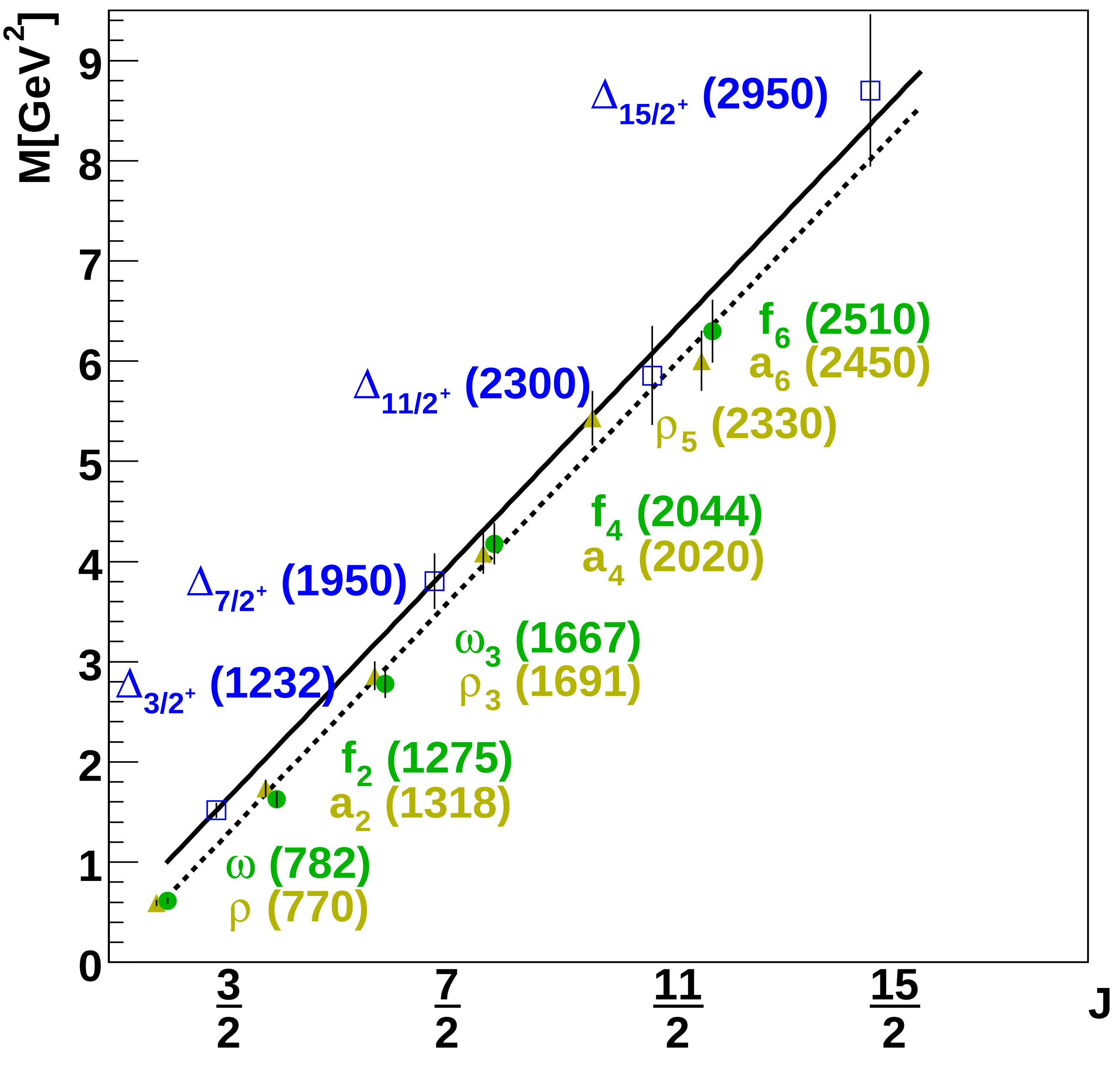
→ **Missing resonances**

→ **Decay properties of resonances**

Phenomenological approach by Regge trajectories

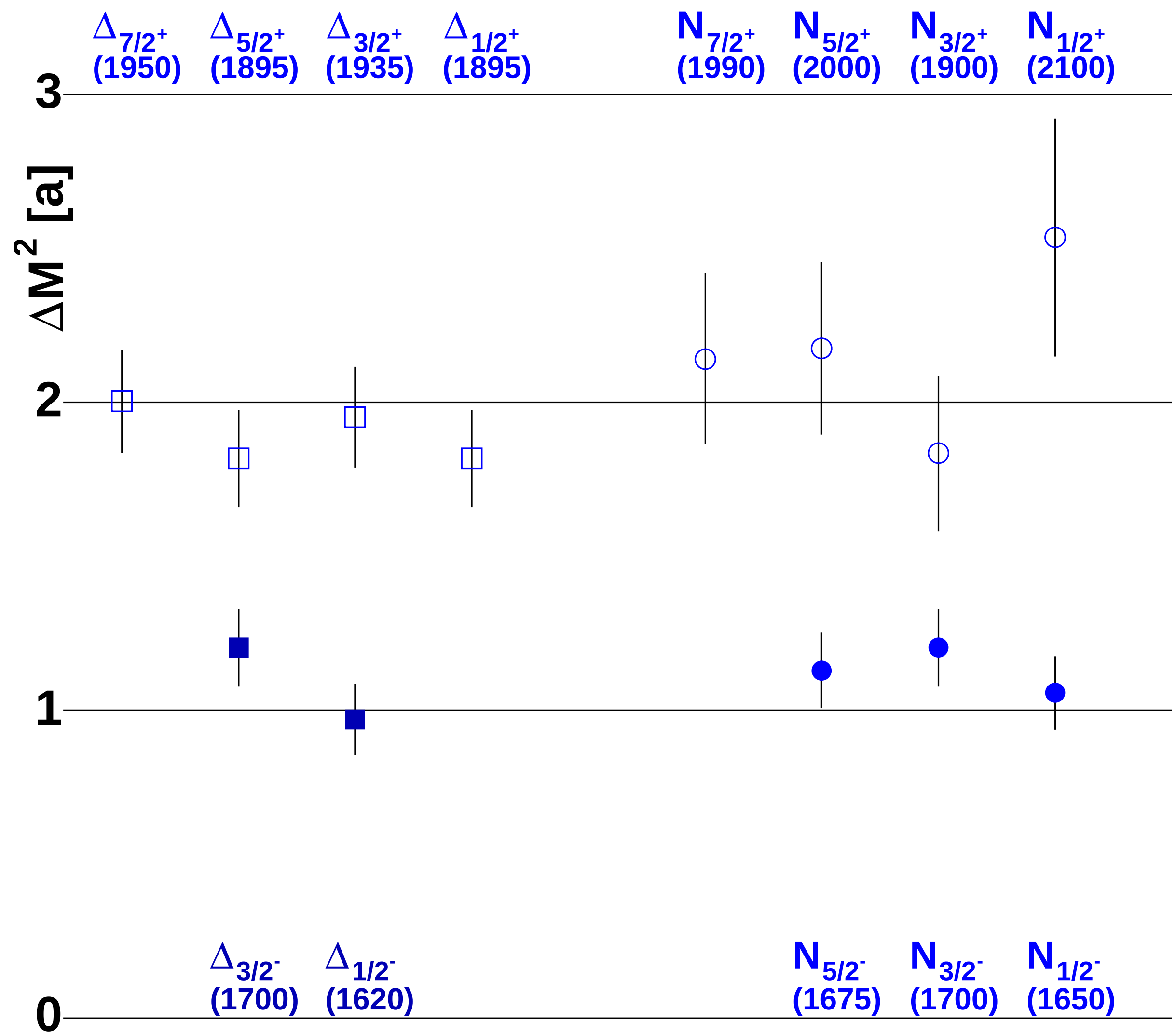


Mesons with J = L+S lie on a Regge trajectory with a slope of 1.142 GeV^2.



Δ^*'s with L even and J = L+3/2 have the same slope as mesons.

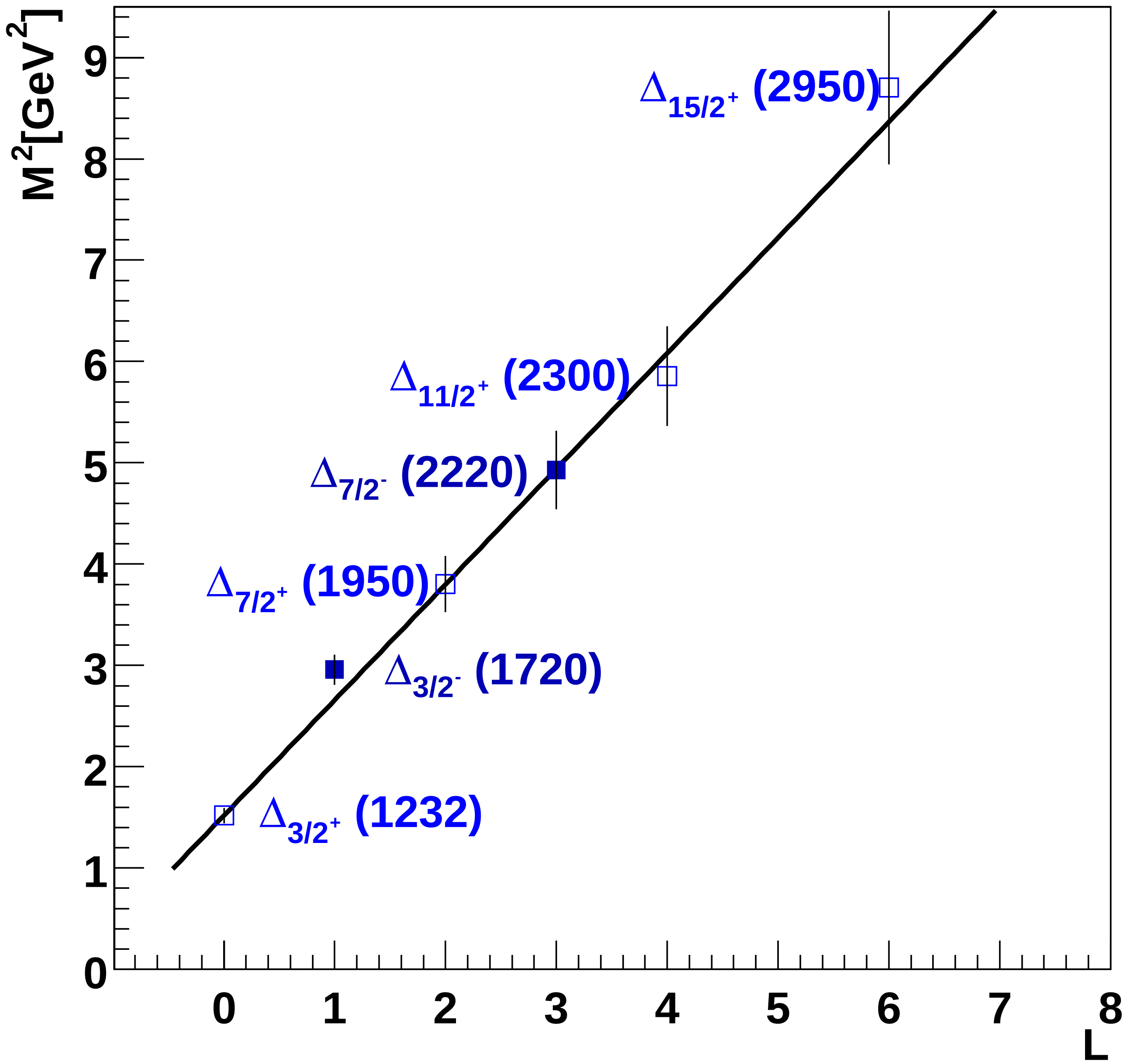
Spin-orbit couplings



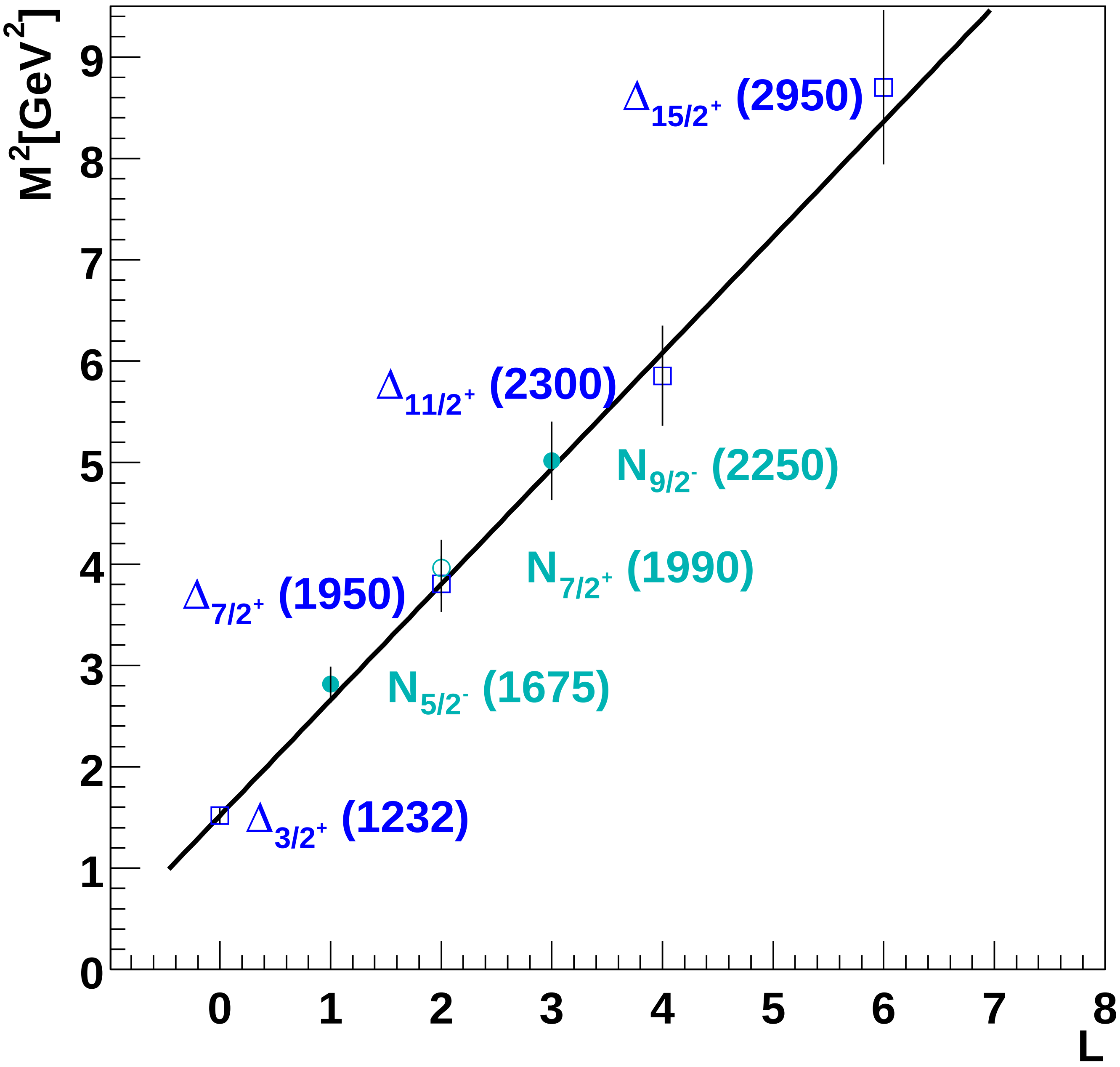
Δ and N resonances assigned to supermultiplets with defined orbital angular momentum.

At 2a:
$\tilde{\mathbf{L}}(\mathbf{2}) + \tilde{\mathbf{S}}(\mathbf{3/2}) = \tilde{\mathbf{J}}(\mathbf{7/2^+}, \mathbf{5/2^+}, \mathbf{3/2^+}, \mathbf{1/2^+})$.

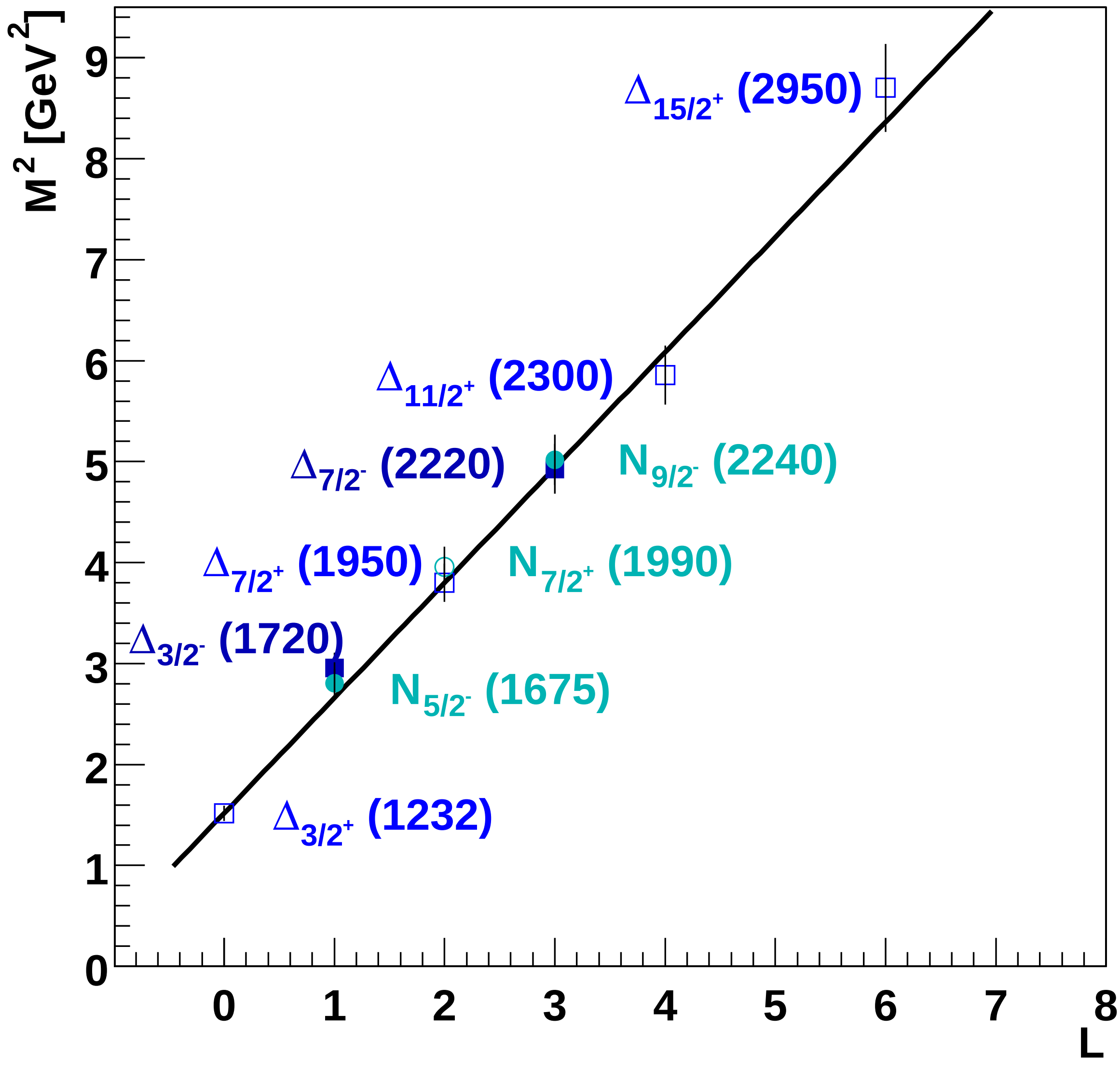
At 1a:
Δ with $\tilde{\mathbf{L}}(\mathbf{1}) + \tilde{\mathbf{S}}(\mathbf{1/2}) = \tilde{\mathbf{J}}(\mathbf{5/2^+}, \mathbf{3/2^+})$
N with $\tilde{\mathbf{L}}(\mathbf{1}) + \tilde{\mathbf{S}}(\mathbf{3/2}) = \tilde{\mathbf{J}}(\mathbf{7/2^+}, \mathbf{5/2^+}, \mathbf{3/2^+})$



Δ^*'s with odd L and J = L + 1/2 fall on the same trajectory.

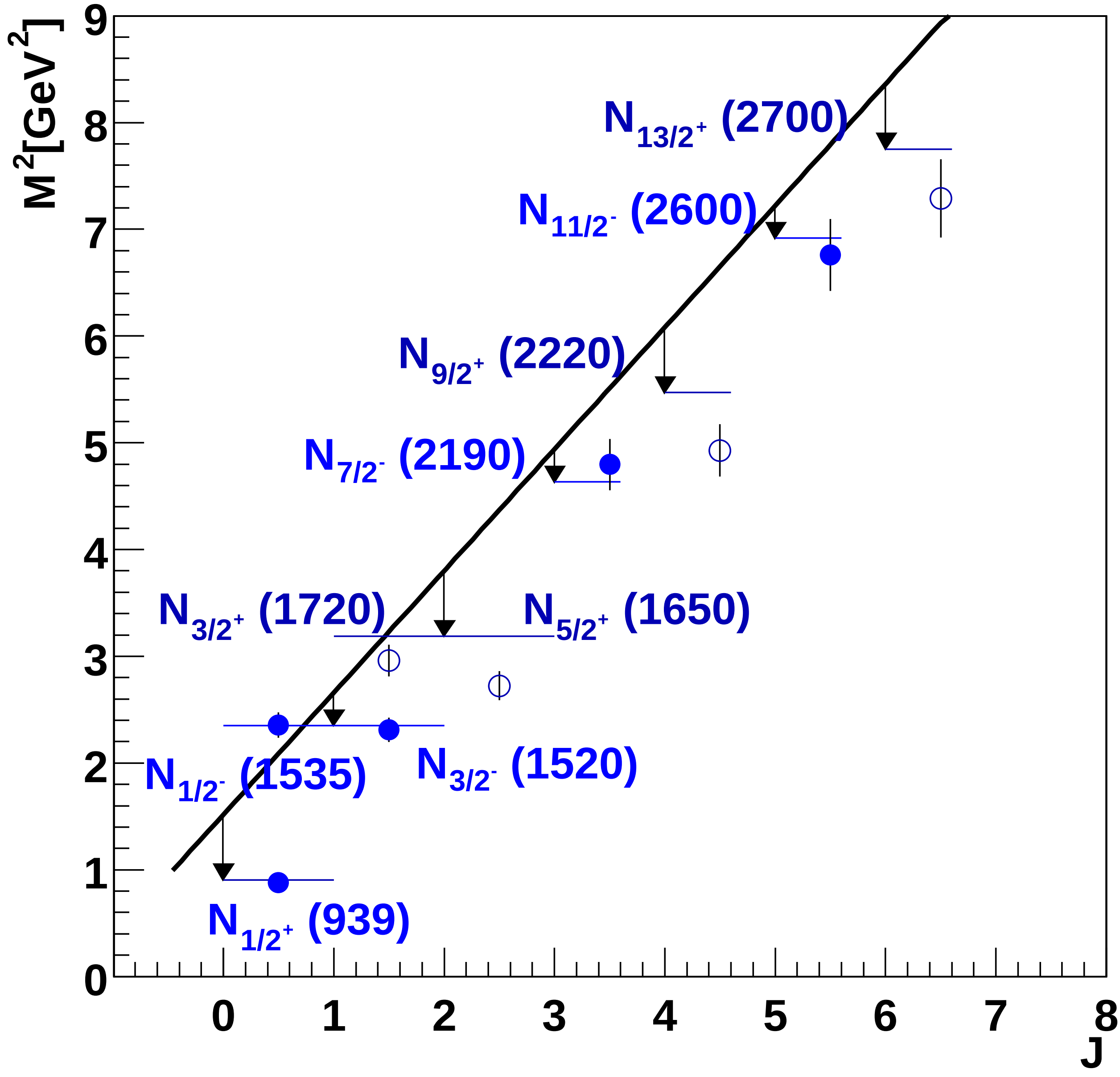


N^*'s with intrinsic spin 3/2 fall on the same trajectory.



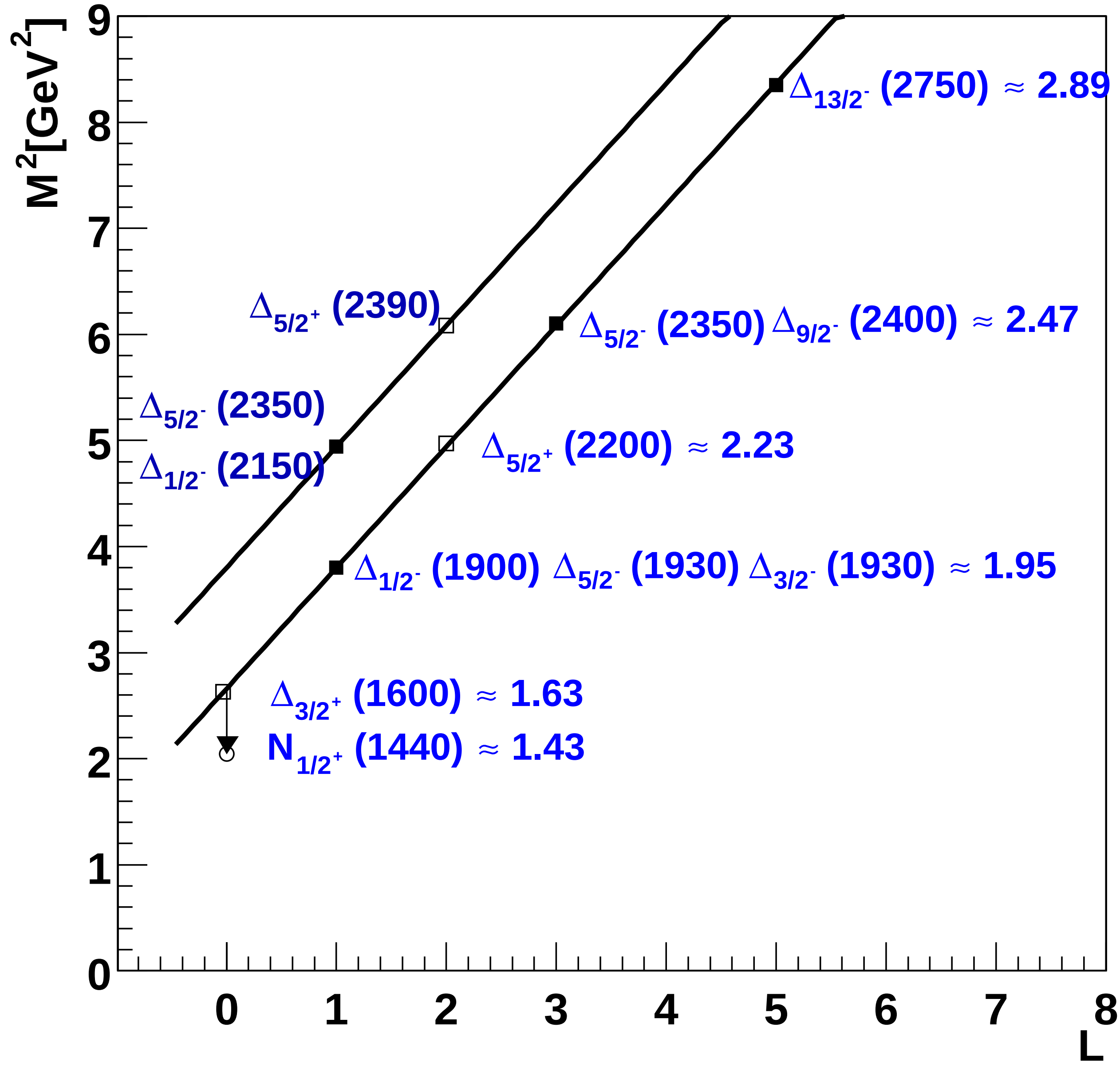
The lowest Δ^* (with spin 1/2 and 3/2) and the N*'s with intrinsic spin 3/2 and J $=$ L $+$ 3/2 fall on the same Regge trajectory.

What is about N* with intrinsic spin $S = 1/2$?



The N* masses (with intrinsic spin $S = 1/2$) lie below the standard Regge trajectory. They are smaller by about 0.6 GeV^2 for N* in the 56-plet, and by 0.3 GeV^2 for N* in the 70-plet.

Radial excitations



Radial excitations have masses larger than the lower mass state by one $\hbar\omega$ (not 2 $\hbar\omega$).

Observations and conclusions

1. The slope of the Regge trajectory for mesons is the same as for Δ^*, $a = 1.142\,\mathrm{GeV}^2$
   $\Rightarrow$ Effective quark - diquark interaction !
2. N and Δ resonances with spin $S = 3/2$ lie on a common Regge trajectory.
   $\Rightarrow$ No significant octet-decuplet splitting.
3. Δ^* resonances with S=1/2 and S=3/2 are on the same Regge trajectory.
   $\Rightarrow$ No significant spin-spin interaction.
4. N^*'s and Δ^*'s can be grouped into supermultiplets with defined L and S but different J.
   $\Rightarrow$ No significant $\tilde{L} \cdot \tilde{S}$ splitting.
5. There is a mass shift $\propto$ to $(q_1q_2 - q_2q_1)(\uparrow\downarrow - \downarrow\uparrow)$ in baryonic wave functions. $\Rightarrow$ Instanton interactions are important.
6. Daughter trajectories have the same slope and an intercept which is higher by $a = 1.142\,\mathrm{GeV}^2$ per n, both for mesons and baryons.
   $\Rightarrow$ Effective quark - diquark interaction !
7. With increasing mass, N^*'s have $J = L + 1/2$;
   Δ^*'s with even J prefer $J = L + 3/2$
   Δ^*'s with odd J prefer $J = L + 1/2$
   $\Rightarrow$ Rotational symmetry dynamically broken !

A new mass formula:

$$M^2 = M_\Delta^2 + \frac{n_s}{3} \cdot M_s^2 + a \cdot (L + N) - s_i \cdot I_{sym}$$

4

n_s number of strange quarks in baryon

L intrinsic orbital angular momentum

$N + 1$ principal quantum number

I_{sym} fraction of wf antisymmetric in spin and flavour:

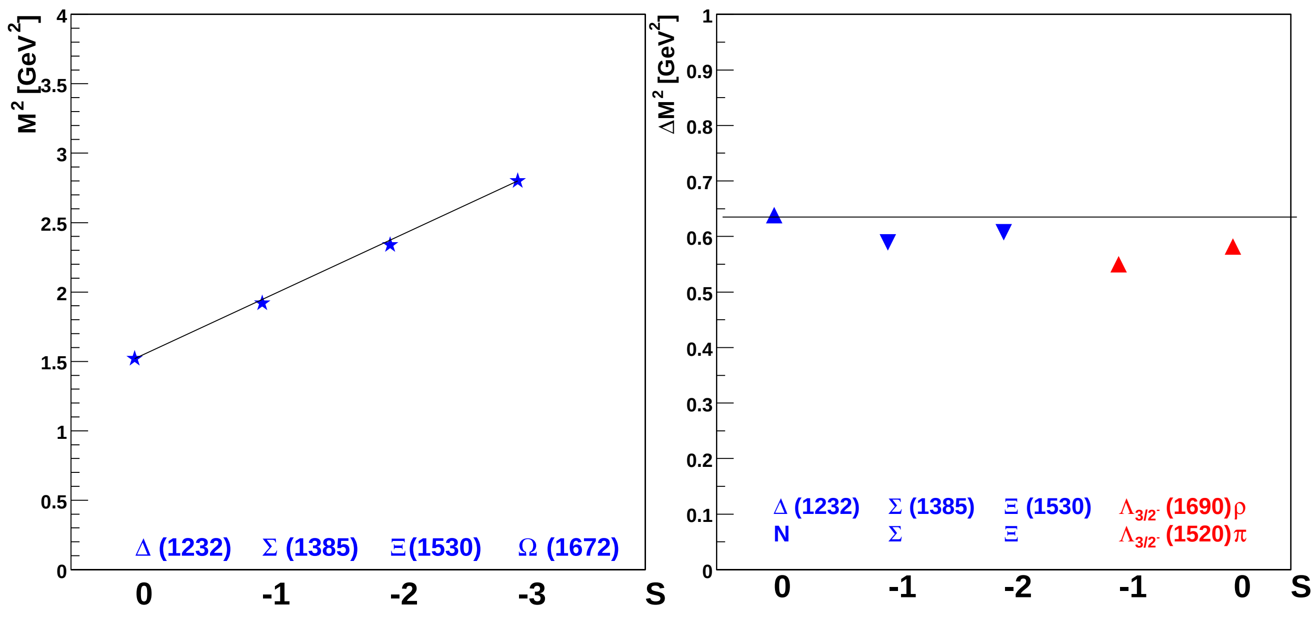
$I_{sym} = 1.0$ for $S = 1/2$ and $N = 56$;
$I_{sym} = 0.5$ for $S = 1/2$ and $N = 70$;
$I_{sym} = 1.5$ for $S = 1/2$ and $N = 1$;
$I_{sym} = 0$ otherwise.

M_Δ^2, M_s^2, s_i, a parameters, fixed from

Baryon masses: N, Δ, Ω

The slope of mesonic Regge trajectory:

$a = 1.142\ GeV^2$


M^2 [GeV^2]
0
0.5
1
1.5
2
2.5
3
3.5
4
Δ (1232)
Σ (1385)
Ξ(1530)
Ω (1672)
0
-1
-2
-3
S
ΔM^2 [GeV^2]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Δ (1232)
N
Σ (1385)
Σ
Ξ (1530)
Ξ
$\Lambda_{3/2^-}$ (1690)ρ
$\Lambda_{3/2^-}$ (1520)π
0
-1
-2
-1
0
S

N*'s

Baryon	Status	D_L	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$N_{1/2^+}(939)$	****	$(56,^2 8)_0$	0	939	-	-	-	-	-
$N_{1/2^+}(1440)$	****	$(56,^2 8)_0$	1	1450	1423	250-450	87	37	0.53
$N_{1/2^+}(1710)$	***	$(56,^2 8)_0$	2	1710	1779	50-250	176	53	1.69
$^1N_{1/2^+}(2100)$	*	$(56,^2 8)_0$	2	2100	2076	-	251	70	0.12
$N_{1/2^-}(1535)$	****	$(70,^2 8)_1$	0	1538	1530	100-250	114	41	0.04
$N_{3/2^-}(1520)$	****	$(70,^2 8)_1$	0	1523	1530	110-135	114	41	0.03
$N_{1/2^-}(1650)$	****	$(70,^4 8)_1$	0	1660	1631	145-190	139	46	0.4
$N_{3/2^-}(1700)$	***	$(70,^4 8)_1$	0	1700	1631	50-150	139	46	2.25
$N_{5/2^-}(1675)$	****	$(70,^4 8)_1$	0	1678	1631	140-180	139	46	1.04
$N_{3/2^+}(1720)$	****	$(56,^2 8)_2$	0	1700	1779	100-200	176	53	2.22
$N_{5/2^+}(1680)$	****	$(56,^2 8)_2$	0	1683	1779	120-140	176	53	3.28
$N_{3/2^+}(1900)$	**	$(70,^4 8)_2$	0	1900	1950	-	219	62	0.65
$N_{5/2^+}(2000)$	**	$(70,^4 8)_2$	0	2000	1950	-	219	62	0.65
$N_{7/2^+}(1990)$	**	$(70,^4 8)_2$	0	1990	1950	-	219	62	0.42
$N_{1/2^-}(2090)$	*	$(70,^2 8)_1$	2	2090	2151	-	269	74	0.68
$N_{3/2^-}(2080)$	**	$(70,^2 8)_1$	2	2080	2151	-	269	74	0.92
$N_{5/2^-}(2200)$	**	$(70,^2 8)_3$	0	2220	2151	-	269	74	0.87
$N_{7/2^-}(2190)$	****	$(70,^2 8)_3$	0	2150	2151	350-550	269	74	0
$N_{9/2^-}(2250)$	****	$(70,^4 8)_3$	0	2240	2223	290-470	287	78	0.05
$N_{9/2^+}(2220)$	****	$(56,^2 8)_4$	0	2245	2334	320-550	315	84	1.12
$N_{11/2^-}(2600)$	***	$(70,^2 8)_5$	0	2650	2629	500-800	389	102	0.04
$N_{13/2^+}(2700)$	**	$(56,^2 8)_6$	0	2700	2781	-	427	111	0.53
						dof:	21	$\sum\chi^2$:	17.53

Δ

Baryon	Status	D_L	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$\Delta_{3/2^+}(1232)$	****	$(56,^4 10)_0$	0	1232	1232	-	-	-	-
$\Delta_{3/2^+}(1600)$	***	$(56,^4 10)_0$	1	1625	1631	250-450	139	46	0.02
$\Delta_{1/2^+}(1750)$	*	$(70,^2 10)_0$	1	1750	1631	-	139	46	6.69
$\Delta_{1/2^-}(1620)$	****	$(70,^2 10)_1$	0	1645	1631	120-180	139	46	0.09
$\Delta_{3/2^-}(1700)$	****	$(70,^2 10)_1$	0	1720	1631	200-400	139	46	3.74
$\Delta_{1/2^-}(1900)$	**	$(56,^4 10)_1$	1	1900	1950	140-240	219	62	0.65
$\Delta_{3/2^-}(1940)$	*	$(56,^4 10)_1$	1	1940	1950	-	219	62	0.03
$\Delta_{5/2^-}(1930)$	***	$(56,^4 10)_1$	1	1945	1950	250-450	219	62	0.01
$\Delta_{1/2^+}(1910)$	****	$(56,^4 10)_2$	0	1895	1950	190-270	219	62	0.79
$\Delta_{3/2^+}(1920)$	***	$(56,^4 10)_2$	0	1935	1950	150-300	219	62	0.06
$\Delta_{5/2^+}(1905)$	****	$(56,^4 10)_2$	0	1895	1950	280-440	219	62	0.79
$\Delta_{7/2^+}(1950)$	****	$(56,^4 10)_2$	0	1950	1950	290-350	219	62	0
$\Delta_{1/2^-}(2150)$	*	$(70,^2 10)_1$	2	2150	2223	-	287	78	0.88
$\Delta_{7/2^-}(2200)$	*	$(70,^2 10)_3$	0	2200	2223	-	287	78	0.09
$^1\Delta_{5/2^+}(2000)$	**	$(70,^2 10)_2$	1	2200	2223	-	287	78	0.09
$\Delta_{5/2^-}(2350)$	*	$(56,^4 10)_1$	0	2350	2467	-	348	92	1.62
$\Delta_{9/2^-}(2400)$	**	$(56,^4 10)_3$	1	2400	2467	-	348	92	0.53
$\Delta_{7/2^+}(2390)$	*	$(56,^4 10)_4$	0	2390	2467	-	348	92	0.7
$\Delta_{9/2^+}(2300)$	**	$(56,^4 10)_4$	0	2300	2467	-	348	92	3.3
$\Delta_{11/2^+}(2420)$	****	$(56,^4 10)_4$	0	2400	2467	300-500	348	92	0.53
$\Delta_{13/2^-}(2750)$	**	$(56,^4 10)_5$	1	2750	2893	-	455	118	1.47
$\Delta_{15/2^+}(2950)$	**	$(56,^4 10)_6$	0	2950	2893	-	455	118	0.23
						dof:	21	$\sum \chi^2$:	22.31

Σ

Baryon	Status	D_L	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$\Sigma_{1/2^+}(1193)$	****	$(56,^2 8)_0$	0	1193	1144	-	-	30	2.67
$\Sigma_{3/2^+}(1385)$	****	$(56,^4 10)_0$	0	1384	1394	-	-	30	0.11
$\Sigma(1480)$	*								
$\Sigma(1560)$	**	$(56,^2 8)_0$	1	1560	1565	-	32	31	0.03
$\Sigma_{1/2^+}(1660)$	***	$(70,^2 8)_0$	1	1660	1664	40-200	57	33	0.01
$\Sigma_{1/2^+}(1770)$	*	$(70,^2 10)_0$	1	1770	1757	-	80	36	0.13
$\Sigma_{1/2^+}(1880)$	**	$(56,^2 8)_0$	2	1880	1895	-	115	42	0.13
$\Sigma_{1/2^-}(1620)$	**	$(70,^2 8)_1$	0	1620	1664	-	57	33	1.78
$\Sigma_{3/2^-}(1580)$	**	$(70,^2 8)_1$	0	1580	1664	-	57	33	6.48
$\Sigma(1690)$	**	$(70,^2 10)_1$	0	1690	1757	-	80	36	3.46
$\Sigma_{1/2^-}(1750)$	***	$(70,^4 8)_1$	0	1765	1757	60-160	80	36	0.05
$\Sigma_{3/2^-}(1670)$	****	$(70,^4 8)_1$	0	1675	1757	40-80	80	36	5.19
$\Sigma_{5/2^-}(1775)$	****	$(70,^4 8)_1$	0	1775	1757	105-135	80	36	0.25
$\Sigma_{1/2^-}(2000)$	*	$(70,^2 8)_1$	1	2000	1977	-	135	45	0.26
$\Sigma_{3/2^-}(1940)$	***	$(70,^2 8)_1$	1	1925	1977	150-300	135	45	1.34
$\Sigma_{3/2^+}(1840)$	*	$(56,^2 8)_0$	2	1840	1895	-	115	42	1.71
$\Sigma_{5/2^+}(1915)$	****	$(56,^2 8)_0$	2	1918	1895	80-160	115	42	0.3
$^1\Sigma_{3/2^+}(2080)$	**	$(56,^4 10)_0$	2	2080	2056	-	155	49	0.24
$^1\Sigma_{5/2^+}(2070)$	*	$(56,^4 10)_0$	2	2070	2058	-	155	49	0.06
$^1\Sigma_{7/2^+}(2030)$	****	$(56,^4 10)_0$	2	2033	2056	150-200	155	49	0.22
$\Sigma(2250)$	***	$(70,^2 8)_3$	0	2245	2248	60-150	203	59	0
$\Sigma_{7/2^-}(2100)$	*	$(70,^2 8)_3$	0	2100	2248	-	203	59	6.29
$\Sigma(2455)$	**	$(56,^2 8)_4$	0	2455	2424	-	247	69	0.2
$\Sigma(2620)$	**	$(70,^2 8)_5$	0	2620	2708	-	318	85	1.07
$\Sigma(3000)$	*	$(56,^2 8)_6$	0	3000	2857	-	355	94	2.31
$\Sigma(3170)$	*	$(70,^2 8)_7$	0	3170	3102	-	416	108	0.4
						dof:	25	$\sum\chi^2$:	34.69

Λ

Baryon	Status	$\mathrm{D_L}$	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$\Lambda_{1/2^+}(1115)$	****	$(56,^2 8)_0$	0	1116	1144	-	-	30	0.87
$\Lambda_{1/2^+}(1600)$	***	$(56,^2 8)_0$	1	1630	1565	50-250	32	31	4.4
$\Lambda_{1/2^+}(1810)$	***	$(56,^2 8)_0$	2	1800	1895	50-250	115	42	5.12
$\Lambda_{1/2^-}(1405)$	****	$(70,^2 1)_1$	0	1407	1460	50	6	30	3.12
$\Lambda_{3/2^-}(1520)$	****	$(70,^2 1)_1$	0	1520	1460	16	6	30	4
$\Lambda_{1/2^-}(1670)$	****	$(70,^2 8)_1$	0	1670	1664	25-50	57	33	0.03
$\Lambda_{3/2^-}(1690)$	****	$(70,^2 8)_1$	0	1690	1664	50-70	57	33	0.62
$\Lambda_{1/2^-}(1800)$	***	$(70,^4 8)_1$	0	1785	1757	200-400	80	36	0.6
$\Lambda_{5/2^-}(1830)$	****	$(70,^4 8)_1$	0	1820	1757	60-110	80	36	3.06
$\Lambda_{3/2^+}(1890)$	****	$(56,^2 8)_2$	0	1880	1895	60-200	115	42	0.13
$\Lambda_{5/2^+}(1820)$	****	$(56,^2 8)_2$	0	1820	1895	70-90	115	42	3.19
$\Lambda(2000)$	*	$(70,^4 8)_2$	0	2000	2056	-	155	49	1.31
$\Lambda_{5/2^+}(2110)$	***	$(70,^4 8)_2$	0	2115	2056	150-250	155	49	1.45
$\Lambda_{7/2^+}(2020)$	*	$(70,^4 8)_2$	0	2020	2056	-	155	49	0.54
$\Lambda_{7/2^-}(2100)$	****	$(70,^2 1)_3$	0	2100	2101	100-250	166	51	0
$\Lambda_{3/2^-}(2325)$	*	$(70,^2 8)_1$	2	2325	2248	-	203	59	1.7
$\Lambda_{9/2^+}(2350)$	***	$(56,^2 8)_4$	0	2355	2424	100-250	247	69	1
$\Lambda(2585)$	**	$(70,^4 8)_2$	0	2585	2551	-	279	76	0.2
						dof:	18	$\sum\chi^2$:	31.34

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Baryon	Status	D_L	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$\Xi_{1/2^+}(1320)$	****	$(56,^2 8)_0$	0	1315	1317	-	-	30	0
$\Xi_{3/2^+}(1530)$	****	$(56,^4 10)_0$	0	1532	1540	9	-	30	0.07
$\Xi(1620)$	*			1620					
$\Xi(1690)$	***	$(56,^2 8)_0$	1	1690	1696	<30	21	30	0.04
$\Xi_{3/2^-}(1820)$	***	$(70,^2 8)_1$	0	1823	1787	14-39	43	32	1.27
$\Xi(1950)$	***	$(56,^2 8)_2$	0	1950	2004	40-80	98	39	1.92
$\Xi(2030)$	***	$(56,^2 8)_2$	0	2025	2004	15-35	98	39	0.29
$\Xi(2120)$	*	$(56,^4 10)_2$	0	2120	2157	-	136	45	0.68
$\Xi(2250)$	**	$(56,^4 10)_2$	0	2250	2157	-	136	45	4.27
$\Xi(2370)$	**	$(70,^2 8)_3$	0	2370	2340	-	182	55	0.3
$\Xi(2500)$	*	$(56,^2 8)_4$	0	2500	2510	-	224	64	0.02
						dof:	10	$\sum\chi^2$:	8.86

Baryon	Status	D_L	N	M_e	M_m	Γ_e	Γ_m	σ	χ^2
$\Omega_{3/2^+}(1672)$	****	$(56,^4 10)_0$	0	1672	-	-	-	-	-
$\Omega(2250)$	****	$(56,^4 10)_2$	0	2252	2254	37-73	77	36	0
$\Omega(2380)$	**	-	-	2380	-	-	-	-	-
$\Omega(2470)$	**	$(56,^2 8)_0$	1	2474	2495	39-105	137	46	0.21
						dof:	2	$\sum\chi^2$:	0.21

- **$\chi^2 = 117$ for 97 data points.**
- **All but 3 observed states are predicted:**

$\Rightarrow$ There are no (baryonic) hybrids!
$\Rightarrow$ There are no pentaquarks!

A NEW MASS FORMULA: INTERPRETATION

Contradiction:

1. **Baryon resonances are quark-diquark excitations**
2. **Baryon resonances need the full multiplet structure**

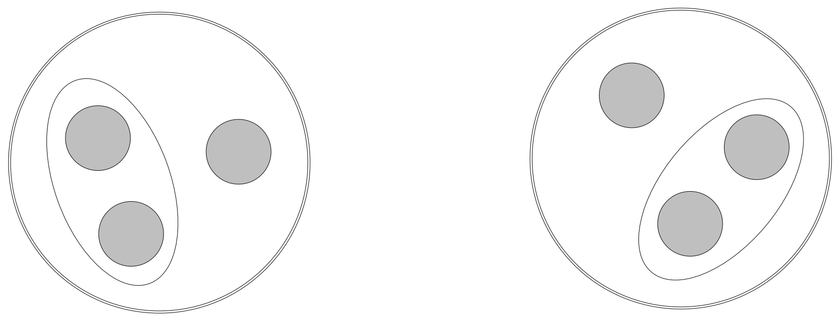
Solution:

1. **refers to the colour interaction**
2. **refers to the flavour decomposition**

Example:

$\mathbf{N_{3/2^-}(1520)}$ $\qquad$ $\mathbf{L = 1 \quad S = 1/2 \rightarrow \; J = 3/2}$

Both harmonic oscillators are coherently excited (in flavour space). Dynamics is given by colour !



Flavour diquark $\neq$ **Colour diquark**

Interactions

1. Confinement

Colour-neutral (Pomeron-like)
Quarks polarise vacuum
Vacuum transmits interaction

When two quarks are separated, the space between them is filled with polarised vacuum. The net colour charge remains unchanged, the energy density is constant. This gives a linear confinement potential.

2. Flavour exchange

$\boldsymbol{\Lambda = 1\,\mathrm{GeV} = \Lambda_{\chi}}$

Meson exchange
with long range
and/or instanton
interactions

3. Colour exchange

$\boldsymbol{\Lambda = 200\,\mathrm{MeV} = \Lambda_{\mathrm{QCD}}}$

Gluon exchange
short range
Screened by
polarised vacuum

Related topics:

1. **Spin crisis**
   Quark spin induces polarisation into condensates;

   the polarised gluon-condensate provides the gluonic contribution to the proton spin

   quark condensate provides the quark and orbital ($^3P_0$) contributions

2. **$^3P_0$ model for decays**
   A $\bar{q}q$ pair from condensate shifted to mass shell

3. **New interpretation of glueballs and hybrids**

   Do hybrids exist ? Does the flux tube filled with polarised condensates support transverse oscillations/rotations ? Or only longitudinal 'acustical' shock waves ?

   Can a state of localised polarised-condensate propagate in space (in a soliton-like solution) ?

4. **Can we approximate QCD in the confinement region ?**

PERHAPS; QUENCHED LQCD AND PQCD ARE NO GUIDELINES !

Summary

- **The excitation spectrum of baryons is very similar to that of mesons.**

  Meson and baryon Regge trajectories have the same slope

  Mesons and baryons have the same spacing in radial excitations.

  The octet-decuplet splitting is the same as the $\rho - \pi$ splitting.

- **The excitation spectrum of baryons is much richer than that of mesons.**

  From meson physics we expect 56-plets for L even, 70-plet for L odd.

  We have 70-plets for L=0 and L=2. Best evidence is from
  $\mathbf{N}_{1/2^+}(2100)$, $\mathbf{N}_{3/2^+}(1900)$, $\mathbf{N}_{5/2^+}(2000)$, $\mathbf{N}_{7/2^+}(1990)$
  and from $\mathbf{\Lambda}_{5/2^+}(2110)$, $\mathbf{\Lambda}_{7/2^+}(2020)$

  We have 56-plets for L odd. Best evidence is from
  $\Delta_{1/2^-}(1900)$, $\Delta_{3/2^-}(1940)$, $\Delta_{5/2^-}(1930)$

- **Flavour symmetry exploits full $\mathbf{O(6)} \otimes \mathbf{SU(6)}$**
  Interaction is due to a quark-diquark.

- **Flavour is not a property of constituent quarks.**
  Vacuum condensates play a decisice role !