Strange particles (disc. ~1950)

[Why strange?]

Particles produced in pairs ("associated production")

w/ typical <u>strong</u> interaction cross-sections ($\sigma \sim 1$ mb)

Decay w/ long mean lives ($\tau \sim 10^{-10}$ s) ← visible tracks : $c\tau \sim$ centimeters

typical of <u>weak</u> interactions

[see photo]

$$\pi^- p \xrightarrow{\text{strong}} \Lambda^0 \xrightarrow{\text{weak}} p\,\pi^-$$

$$\phantom{\pi^- p \xrightarrow{\text{strong}}} K^0 \xrightarrow{\text{weak}} \pi^+\pi^-$$

[unlike $\Delta \to pN$ or $\rho \to \pi\pi$ w/ short mean lives]

1953 Gell Mann, Nishijima independently explained the strange behavior by hypothesizing a new quantum number, S (strangeness) that is <u>conserved</u> by strong (and electromagnetic) interactions

(so $\Delta S = 0$)

but <u>can be violated</u> by weak interactions

(so ΔS can be $\neq 0$)

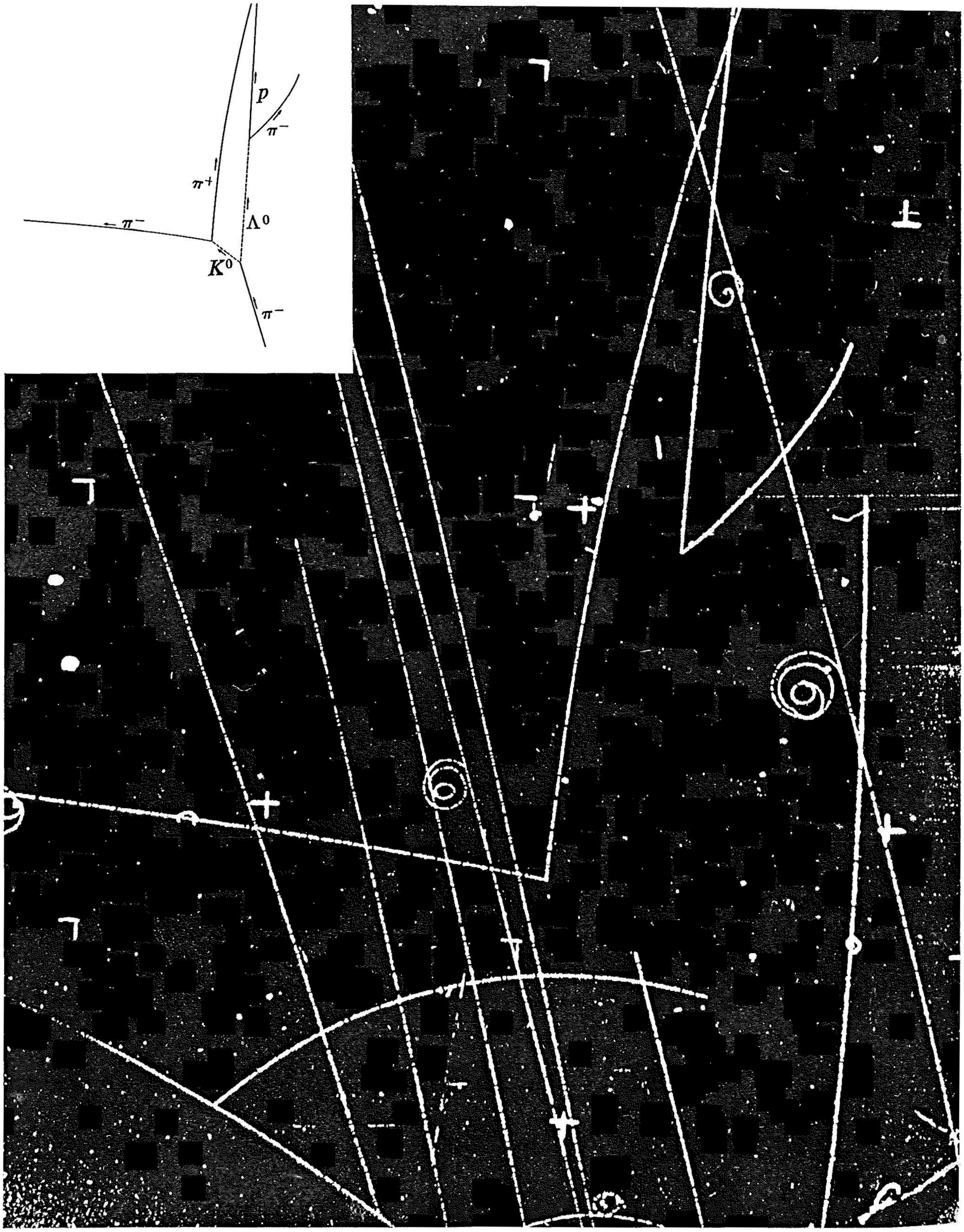


Figure 15-3 Bubble-chamber picture showing the following reactions:

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

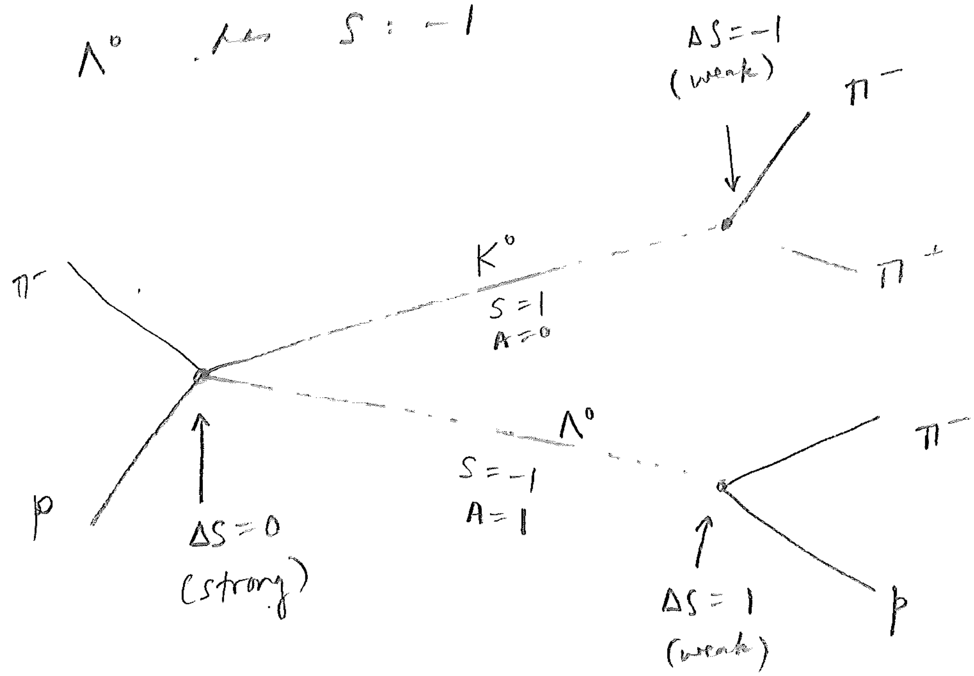
[Courtesy Lawrence Radiation Laboratory, Berkeley, Calif.]

in Segrè

All previously known particles have $S = 0$

K^0 has $S = 1$

Λ^0 has $S = -1$



Other strange mesons were produced

STRANGE BARYONS (S = −1)	I	J	m (MeV)	decay
Λ^0	0	$\frac{1}{2}$	~1100	weak
$\Sigma^+, \Sigma^0, \Sigma^-$	1	$\frac{1}{2}$	~1200	weak/EM
$\Sigma^{+*}, \Sigma^{0*}, \Sigma^{-*}$	1	$\frac{3}{2}$	~1380	strong

STRANGE MESONS (S = 1)	I	J	m (MeV)	decay
K^+, K^0	$\frac{1}{2}$	0	~500	weak
K^{+*}, K^{0*}	$\frac{1}{2}$	1	~900	strong

[Note: baryons in singlets, mesons in triplets, opposite to before]

Gell-mann Nishijima relation: $q = I_3 + \frac{1}{2}A + \frac{1}{2}S$

All standard model interactions conserve q and A

Strong interactions conserve also isospin and strangeness

Weak interactions may violate strangeness, and also I, I_3

Electromagnetism conserve strangeness, and $\therefore$ also I_3 but not necessarily I

$$\Sigma^0 \xrightarrow[\Delta S = 0]{EM} \Lambda^0 \ \gamma \qquad [100\%]$$

Σ^0: $I = 1$

Λ^0: $I = 0$

γ: has no isospin

conserved?

	Q	A	I	I_3	S
strong	✓	✓	✓	✓	✓
EM	✓	✓		✓	✓
weak	✓	✓			

Decays of strange particles

K must decay weakly because they are lightest strange particles

$$K \xrightarrow[\Delta S \neq 0]{\text{weak}} \pi\pi$$

$$K^* \xrightarrow[\Delta S = 0]{\text{strong}} K\pi \qquad (\text{analogous to } \rho \to \pi\pi)$$

$$\Lambda^0 \xrightarrow[\Delta S \neq 0]{\text{weak}} N\pi \qquad (\text{lightest strange baryon})$$

$\Lambda^0 \not\xrightarrow{\text{strong}} N \ \bar{K}$ violates energy conservation

Λ^0: $S=-1$, $A=1$; N: $A=1$; $\bar{K}$: $S=-1$

$$\Sigma \not\xrightarrow[\Delta S = 0]{\text{strong}} \Lambda^0 \pi$$, not the lightest baryon but violates energy conservation

$$\Sigma \xrightarrow[\Delta S \neq 0]{\text{weak}} N\pi$$ violates strangeness & also isospin

$N\pi$ is tensor product $\underset{\sim}{2} \otimes \underset{\sim}{3} = \underset{\sim}{4} \oplus \underset{\sim}{2}$
but Σ belongs to $\underset{\sim}{3}$

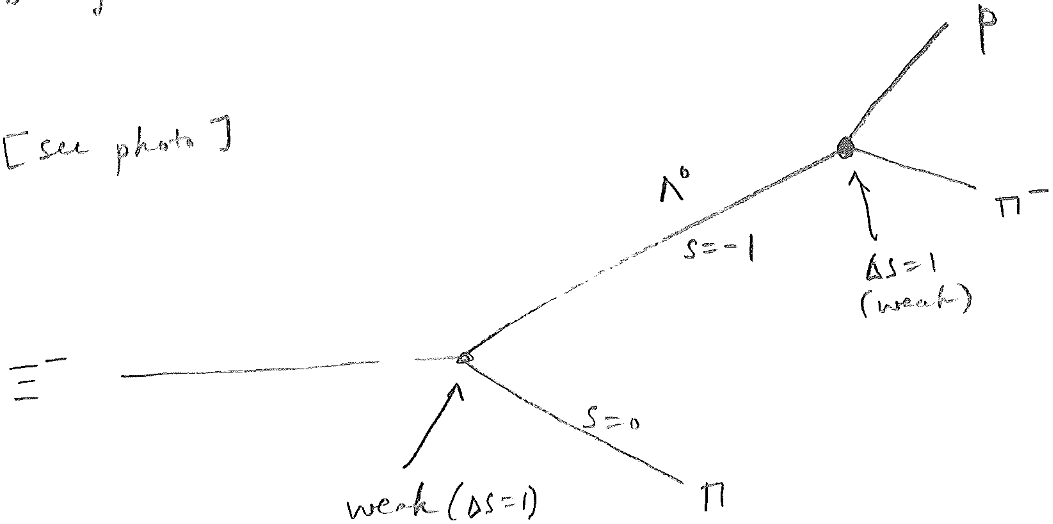
$$\Sigma^* \xrightarrow[\Delta S = 0]{\text{strong}} \Sigma\pi \qquad (\text{analogous to } \Delta \to N\pi)$$

energy conservation OK.

Cascade particles

decays weakly into strange particles

[see photo]



Ξ^- has a track cm long, so decays weakly

Suggest $S=-2$ for Ξ^- (doubly strange)

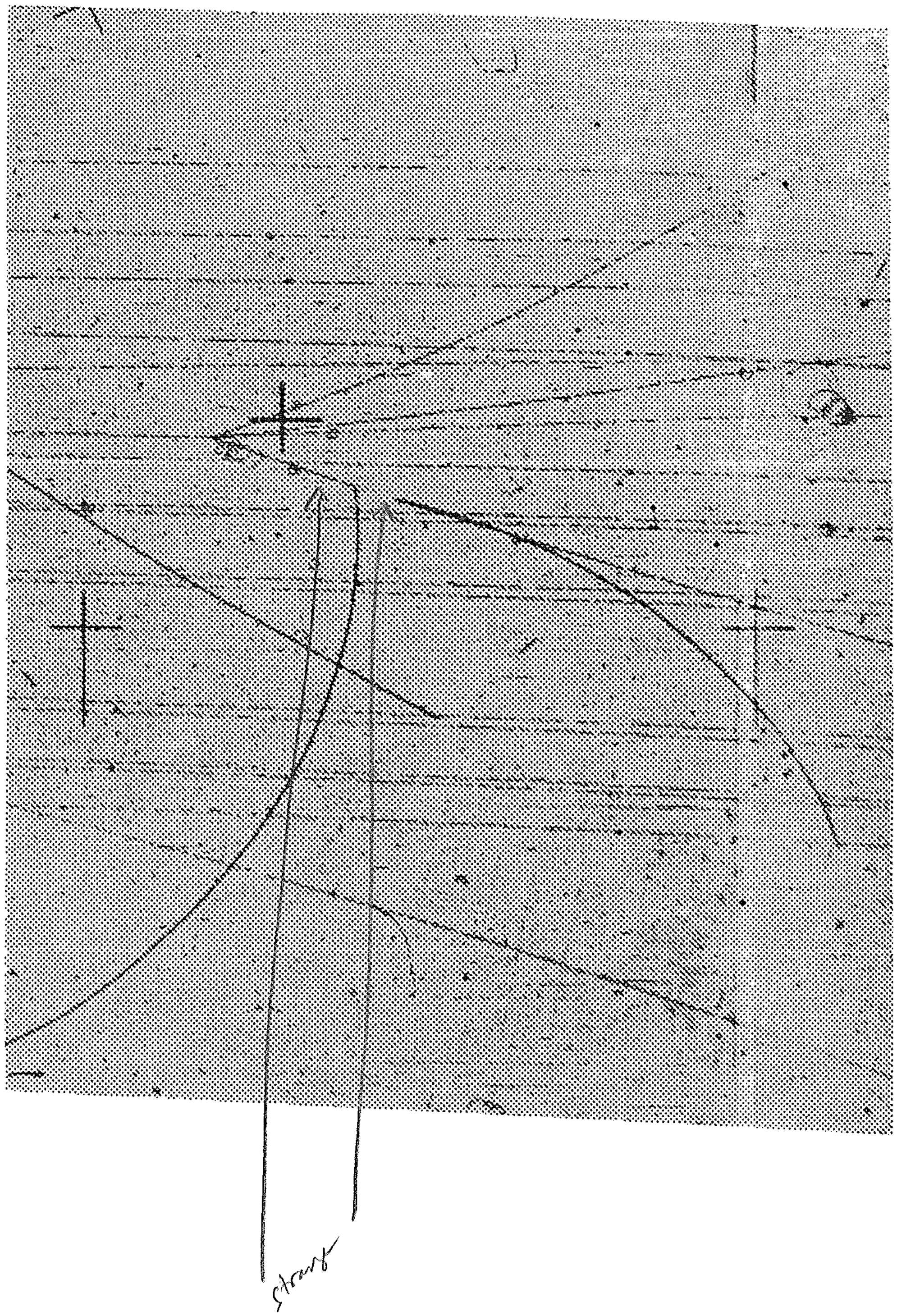
[presumably produced by ? $\longrightarrow \Xi^- K^+ K^-$]

$$q = I_3 + \tfrac{1}{2}A + \tfrac{1}{2}S$$
$$-1 = I_3 + \tfrac{1}{2} + \tfrac{1}{2}(-2) \implies I_3 = -\tfrac{1}{2}$$

belongs to an iso doublet

DOUBLY STRANGE BARYONS ($S=-2$)

	I	J	m	decay
Ξ^0, Ξ^-	$\frac{1}{2}$	$\frac{1}{2}$	~ 1300	weak
Ξ^{0*}, Ξ^{-*}	$\frac{1}{2}$	$\frac{3}{2}$	~ 1530	strong ($\Xi^* \to \Xi\pi$)


strange

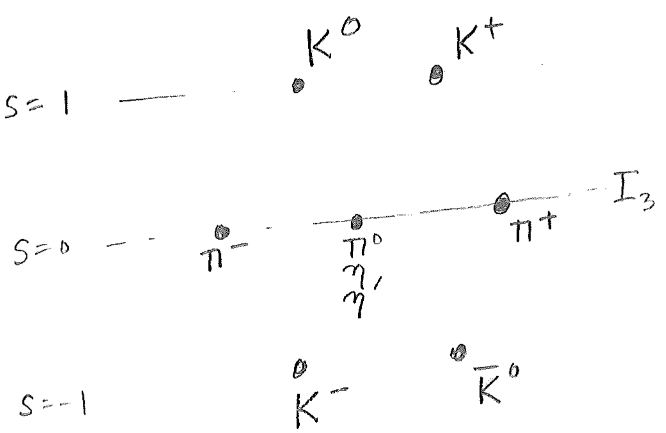
The finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a 10,000 dollar fine.

–Willis Lamb (1955)

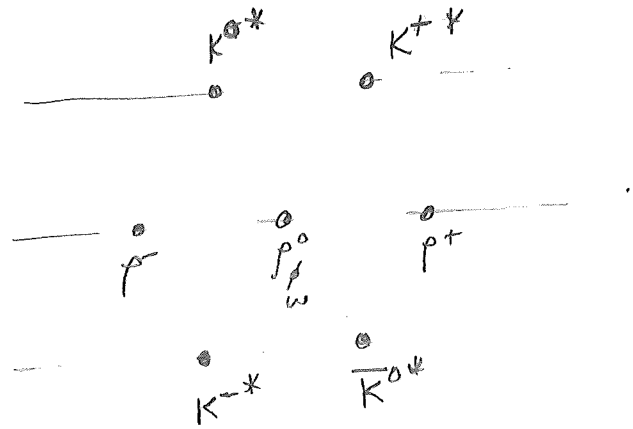
All hadrons belong to isospin multiplets, i.e. representations of SU(2) which are approximately degenerate

[Put all particles on a diagram w/ axes I_3 and S]
[Do $S=0$ first]

Scalar ($J=0$) mesons

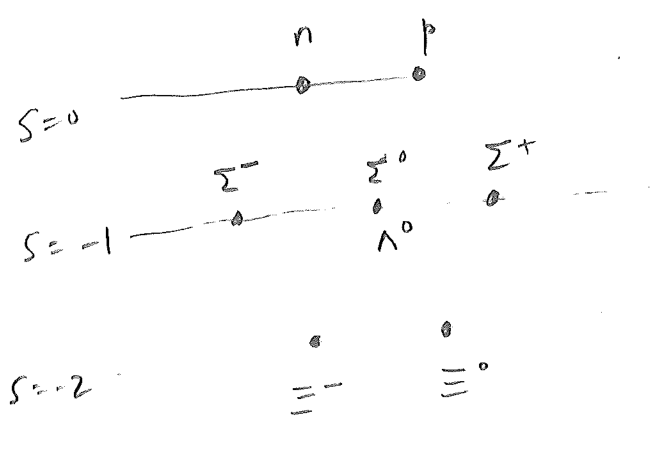


vector ($J=1$) mesons



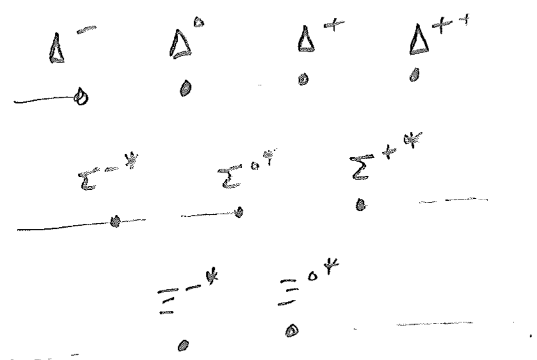
meson "nonets"

$J=\frac{1}{2}$ baryons



baryon "octet"

$J=\frac{3}{2}$ baryons

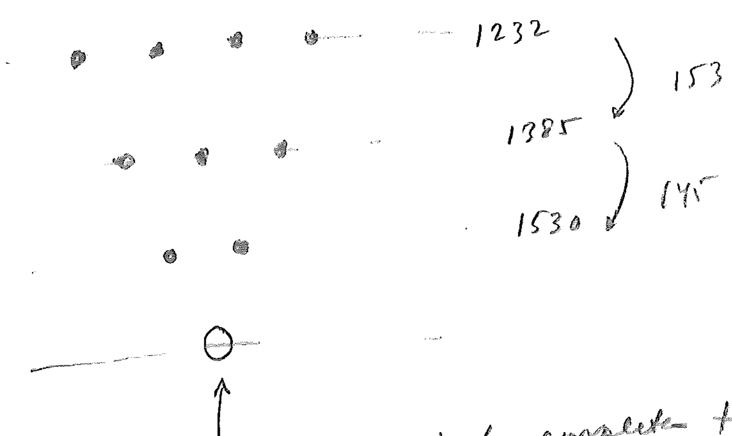


View these as supermultiplets

1961 Gell-Mann recognized these diagrams as weight diagrams of representations of SU(3), a flavor symmetry that generalizes isospin, a.k.a. SU(2)

Approximate isospin symmetry ⇒ isomultiplets are almost degenerate

Even more approximate SU(3) symmetry ⇒ supermultiplets are (not quite as) degenerate



missing state, which completes the SU(3) decuplet

baryon "decuplet"

1961 Gell-Mann predicted the existence of a new particle which he called the Ω.

Let's predict its properties

$S = -3$

$J = \frac{3}{2}$

$I = 0$

$I_3 = 0$

$q = I_3 + \frac{1}{2}A + \frac{1}{2}S$

$= 0 + \frac{1}{2} - \frac{3}{2} = -1$

$m \sim 1675$ MeV

$\therefore$ it would decay weakly $\Omega^- \xrightarrow[\Delta S = 1]{} \Xi^0 \pi^-$

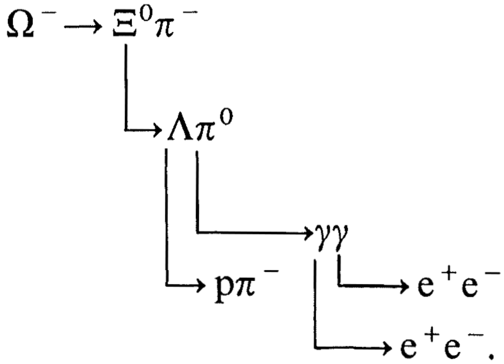
[why not $\Xi^0 K^-$?]
$\quad$ 1300 $\;$ 500

1964 discovered BNL $\quad m = 1672$ MeV

$\tau = 8 \times 10^{-11}$ s

[photo]

[$K^- p \xrightarrow{\text{strong}} K^+ K^0 \Omega^-$]



Many examples of Ω^--particles decaying in each of the three modes have now been observed and, indeed, a 'beam' of highly-relativistic strange baryons including Ω^- has been developed at CERN. The best values of the mass and lifetime are

$$M_{\Omega^-} = 1672.43 \pm 0.32\,\text{MeV}/c^2$$
$$\tau_{\Omega^-} = (0.822 \pm 0.012) \times 10^{-10}\,\text{s}.$$

The spin of the Ω^- has also been measured from the angular distribution of its decay products (see section 9.3) and found to be $\frac{3}{2}$.

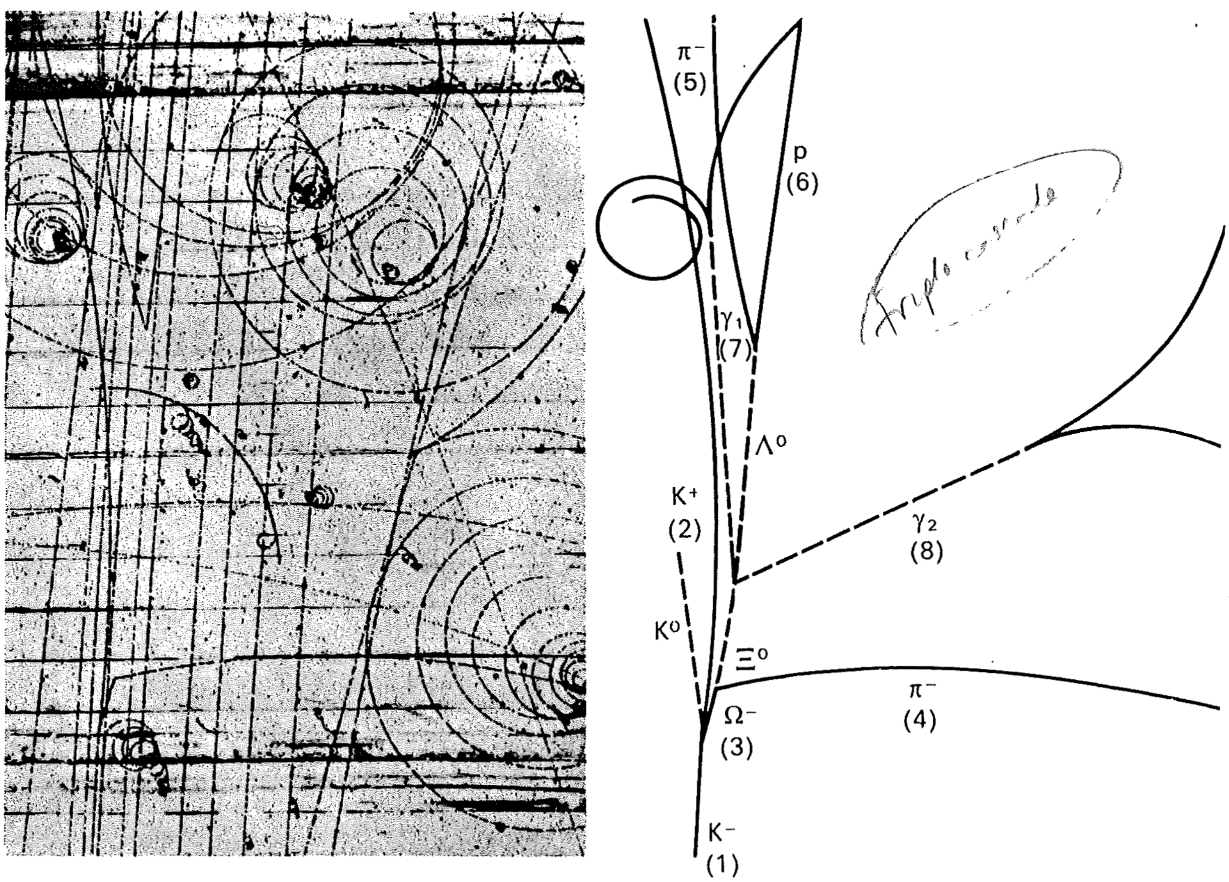
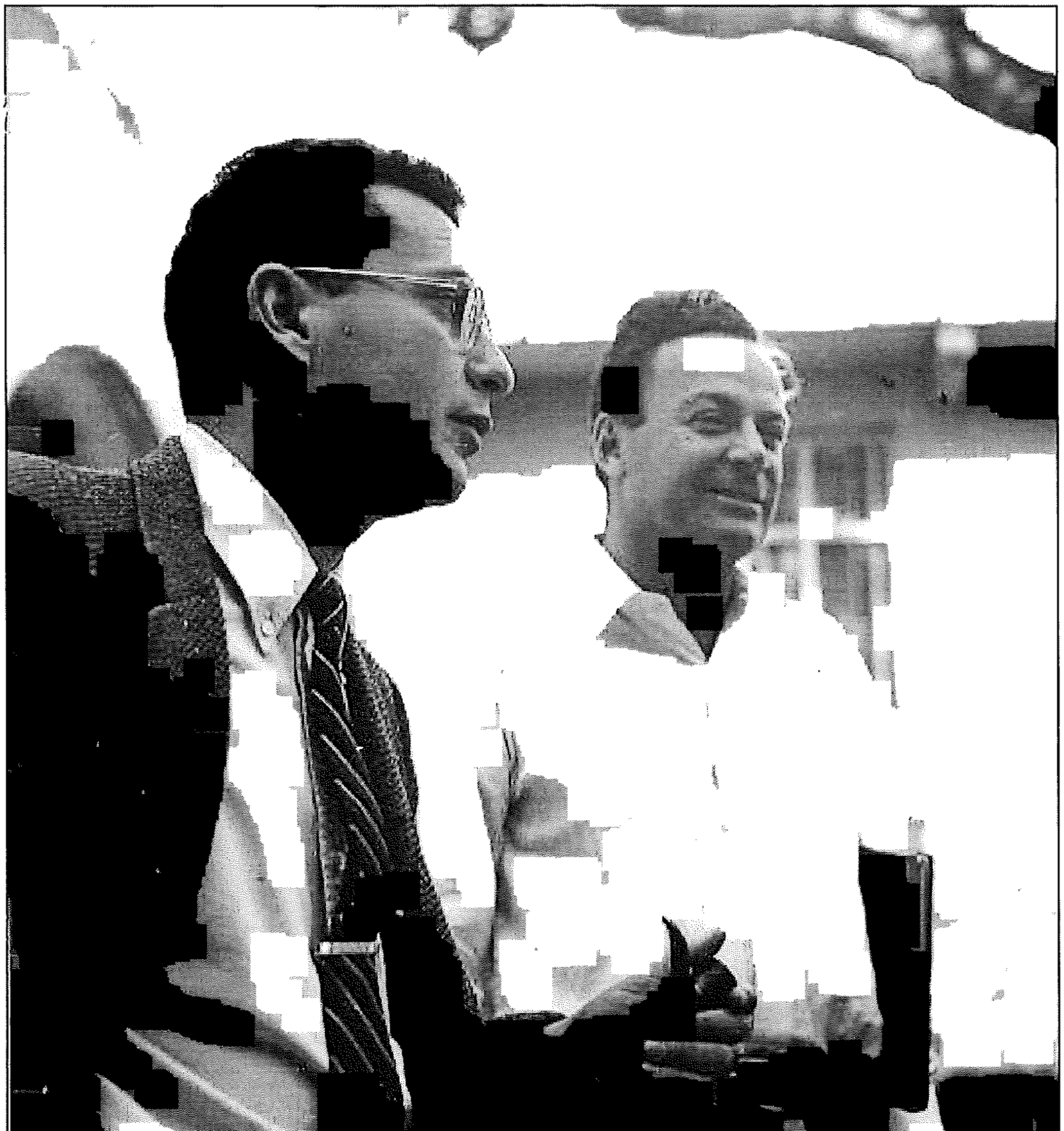
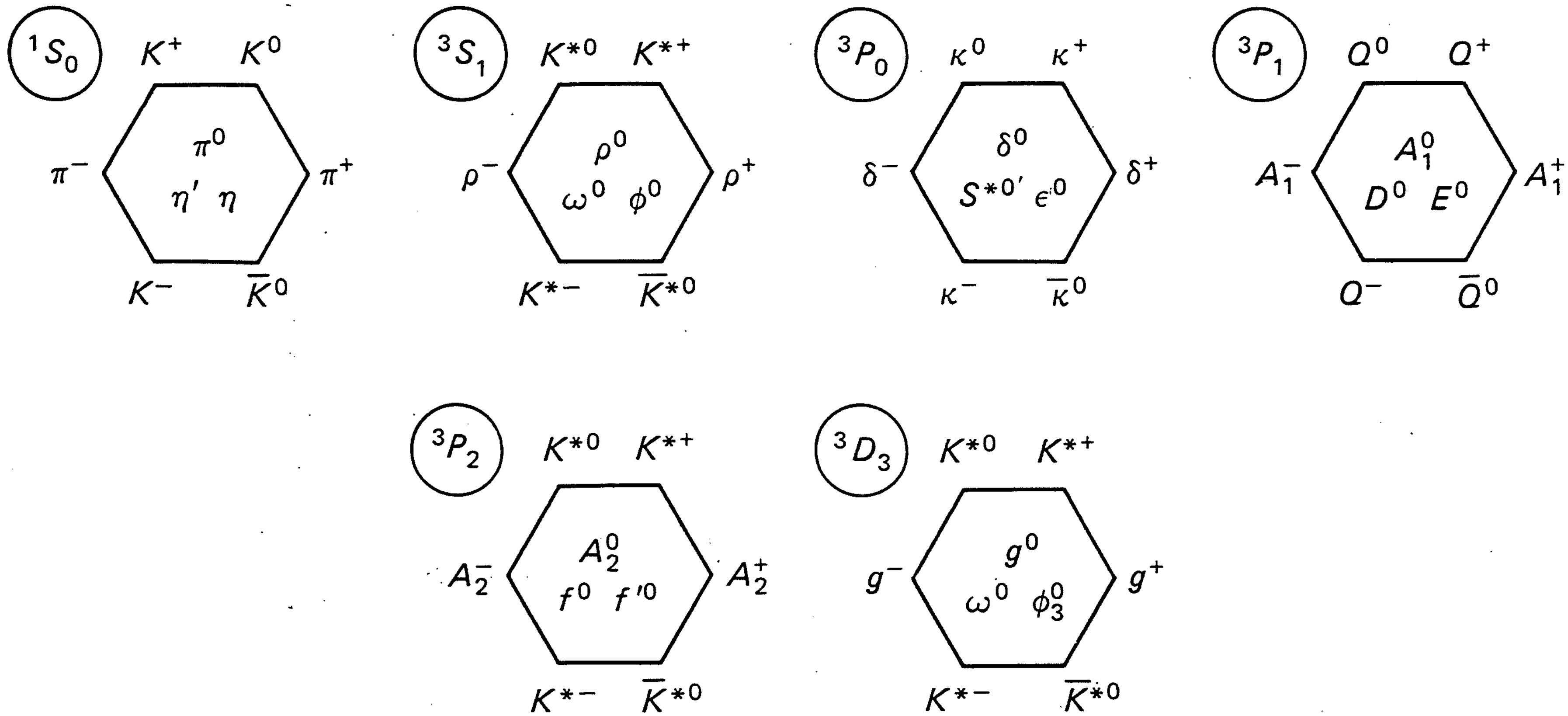


Fig. 5.8. The first Ω^--particle to be observed (Brookhaven National Laboratory, 1964).





$^1S_0$
K^+ K^0
π^- π^0 π^+
η' η
K^- $\bar{K}^0$
$^3S_1$
K^{*0} K^{*+}
ρ^- ρ^0 ρ^+
ω^0 ϕ^0
K^{*-} $\bar{K}^{*0}$
$^3P_0$
κ^0 κ^+
δ^- δ^0 δ^+
$S^{*0'}$ ϵ^0
κ^- $\bar{\kappa}^0$
$^3P_1$
Q^0 Q^+
A_1^- A_1^0 A_1^+
D^0 E^0
Q^- $\bar{Q}^0$
$^3P_2$
K^{*0} K^{*+}
A_2^- A_2^0 A_2^+
f^0 f'^0
K^{*-} $\bar{K}^{*0}$
$^3D_3$
K^{*0} K^{*+}
g^- g^0 g^+
ω^0 ϕ_3^0
K^{*-} $\bar{K}^{*0}$

2004

Baryon Summary Table

This short table gives the name, the quantum numbers (where known), and the status of baryons in the Review. Only the baryons with 3- or 4-star status are included in the main Baryon Summary Table. Due to insufficient data or uncertain interpretation, the other entries in the short table are not established as baryons. The names with masses are of baryons that decay strongly. For N, Δ, and Ξ resonances, the partial wave is indicated by the symbol $L_{2I,2J}$, where L is the orbital angular momuntum (S, P, D, ...); I is the isospin, and J is the total angular momentum. For Λ and Σ resonances, the symbol is $L_{I,2J}$.

p	P_{11}	****	$\Delta(1232)$	P_{33}	****	Λ	P_{01}	****	Σ^+	P_{11}	****	Ξ^0	P_{11}	****
n	P_{11}	****	$\Delta(1600)$	P_{33}	***	$\Lambda(1405)$	S_{01}	****	Σ^0	P_{11}	****	Ξ^-	P_{11}	****
$N(1440)$	P_{11}	****	$\Delta(1620)$	S_{31}	****	$\Lambda(1520)$	D_{03}	****	Σ^-	P_{11}	****	$\Xi(1530)$	P_{13}	****
$N(1520)$	D_{13}	****	$\Delta(1700)$	D_{33}	****	$\Lambda(1600)$	P_{01}	***	$\Sigma(1385)$	P_{13}	****	$\Xi(1620)$		*
$N(1535)$	S_{11}	****	$\Delta(1750)$	P_{31}	*	$\Lambda(1670)$	S_{01}	****	$\Sigma(1480)$		*	$\Xi(1690)$		***
$N(1650)$	S_{11}	****	$\Delta(1900)$	S_{31}	**	$\Lambda(1690)$	D_{03}	****	$\Sigma(1560)$		**	$\Xi(1820)$	D_{13}	***
$N(1675)$	D_{15}	****	$\Delta(1905)$	F_{35}	****	$\Lambda(1800)$	S_{01}	***	$\Sigma(1580)$	D_{13}	**	$\Xi(1950)$		***
$N(1680)$	F_{15}	****	$\Delta(1910)$	P_{31}	****	$\Lambda(1810)$	P_{01}	***	$\Sigma(1620)$	S_{11}	**	$\Xi(2030)$		***
$N(1700)$	D_{13}	***	$\Delta(1920)$	P_{33}	***	$\Lambda(1820)$	F_{05}	****	$\Sigma(1660)$	P_{11}	***	$\Xi(2120)$		*
$N(1710)$	P_{11}	***	$\Delta(1930)$	D_{35}	***	$\Lambda(1830)$	D_{05}	****	$\Sigma(1670)$	D_{13}	****	$\Xi(2250)$		**
$N(1720)$	P_{13}	****	$\Delta(1940)$	D_{33}	*	$\Lambda(1890)$	P_{03}	****	$\Sigma(1690)$		**	$\Xi(2370)$		**
$N(1900)$	P_{13}	**	$\Delta(1950)$	F_{37}	****	$\Lambda(2000)$		*	$\Sigma(1750)$	S_{11}	***	$\Xi(2500)$		*
$N(1990)$	F_{17}	**	$\Delta(2000)$	F_{35}	**	$\Lambda(2020)$	F_{07}	*	$\Sigma(1770)$	P_{11}	*			
$N(2000)$	F_{15}	**	$\Delta(2150)$	S_{31}	*	$\Lambda(2100)$	G_{07}	****	$\Sigma(1775)$	D_{15}	****	Ω^-		****
$N(2080)$	D_{13}	**	$\Delta(2200)$	G_{37}	*	$\Lambda(2110)$	F_{05}	***	$\Sigma(1840)$	P_{13}	*	$\Omega(2250)^-$		***
$N(2090)$	S_{11}	*	$\Delta(2300)$	H_{39}	**	$\Lambda(2325)$	D_{03}	*	$\Sigma(1880)$	P_{11}	**	$\Omega(2380)^-$		**
$N(2100)$	P_{11}	*	$\Delta(2350)$	D_{35}	*	$\Lambda(2350)$	H_{09}	***	$\Sigma(1915)$	F_{15}	****	$\Omega(2470)^-$		**
$N(2190)$	G_{17}	****	$\Delta(2390)$	F_{37}	*	$\Lambda(2585)$		**	$\Sigma(1940)$	D_{13}	***			
$N(2200)$	D_{15}	**	$\Delta(2400)$	G_{39}	**				$\Sigma(2000)$	S_{11}	*	Λ_c^+		****
$N(2220)$	H_{19}	****	$\Delta(2420)$	$H_{3,11}$	****				$\Sigma(2030)$	F_{17}	****	$\Lambda_c(2593)^+$		***
$N(2250)$	G_{19}	****	$\Delta(2750)$	$I_{3,13}$	**				$\Sigma(2070)$	F_{15}	*	$\Lambda_c(2625)^+$		***
$N(2600)$	$I_{1,11}$	***	$\Delta(2950)$	$K_{3,15}$	**				$\Sigma(2080)$	P_{13}	**	$\Lambda_c(2765)^+$		*
$N(2700)$	$K_{1,13}$	**							$\Sigma(2100)$	G_{17}	*	$\Lambda_c(2880)^+$		**
			$\Theta(1540)^+$		***				$\Sigma(2250)$		***	$\Sigma_c(2455)$		****
			$\Phi(1860)$		*				$\Sigma(2455)$		**	$\Sigma_c(2520)$		***
									$\Sigma(2620)$		**	Ξ_c^+		***
									$\Sigma(3000)$		*	Ξ_c^0		***
									$\Sigma(3170)$		*	$\Xi_c'^+$		***
												$\Xi_c'^0$		***
												$\Xi_c(2645)$		***
												$\Xi_c(2790)$		***
												$\Xi_c(2815)$		***
												Ω_c^0		***
												Ξ_{cc}^+		*
												Λ_b^0		***
												Ξ_b^0, Ξ_b^-		*

22·2 = 44   22·4 + Θ + φ   18   26·3   11·2 + 4 +

**** Existence is certain, and properties are at least fairly well explored.

*** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined.

** Evidence of existence is only fair.

* Evidence of existence is poor.

2004

See also the table of suggested $q\overline{q}$ quark-model assignments in the Quark Model section.

• Indicates particles that appear in the preceding Meson Summary Table. We do not regard the other entries as being established.

† Indicates that the value of J given is preferred, but needs confirmation.

LIGHT UNFLAVORED ($S = C = B = 0$)

	$I^G(J^{PC})$		$I^G(J^{PC})$
• $\pi^{\pm}$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
• $\phi(1020)$	$0^-(1^{--})$	• $\phi_3(1850)$	$0^-(3^{--})$
• $h_1(1170)$	$0^-(1^{+-})$	$\eta_2(1870)$	$0^+(2^{-+})$
• $b_1(1235)$	$1^+(1^{+-})$	$\rho(1900)$	$1^+(1^{--})$
• $a_1(1260)$	$1^-(1^{++})$	$f_2(1910)$	$0^+(2^{++})$
• $f_2(1270)$	$0^+(2^{++})$	• $f_2(1950)$	$0^+(2^{++})$
• $f_1(1285)$	$0^+(1^{++})$	$\rho_3(1990)$	$1^+(3^{--})$
• $\eta(1295)$	$0^+(0^{-+})$	• $f_2(2010)$	$0^+(2^{++})$
• $\pi(1300)$	$1^-(0^{-+})$	$f_0(2020)$	$0^+(0^{++})$
• $a_2(1320)$	$1^-(2^{++})$	• $a_4(2040)$	$1^-(4^{++})$
• $f_0(1370)$	$0^+(0^{++})$	• $f_4(2050)$	$0^+(4^{++})$
$h_1(1380)$	$?^-(1^{+-})$	$\pi_2(2100)$	$1^-(2^{-+})$
• $\pi_1(1400)$	$1^-(1^{-+})$	$f_0(2100)$	$0^+(0^{++})$
• $\eta(1405)$	$0^+(0^{-+})$	$f_2(2150)$	$0^+(2^{++})$
• $f_1(1420)$	$0^+(1^{++})$	$\rho(2150)$	$1^+(1^{--})$
• $\omega(1420)$	$0^-(1^{--})$	$f_0(2200)$	$0^+(0^{++})$
$f_2(1430)$	$0^+(2^{++})$	$f_J(2220)$	$0^+(2^{++}$ or $4^{++})$
• $a_0(1450)$	$1^-(0^{++})$		
• $\rho(1450)$	$1^+(1^{--})$	$\eta(2225)$	$0^+(0^{-+})$
• $\rho(1450)$	$0^+(0^{-+})$	$\rho_3(2250)$	$1^+(3^{--})$
• $f_0(1500)$	$0^+(0^{++})$	• $f_2(2300)$	$0^+(2^{++})$
$f_1(1510)$	$0^+(1^{++})$	$f_4(2300)$	$0^+(4^{++})$
• $f_2'(1525)$	$0^+(2^{++})$	• $f_2(2340)$	$0^+(2^{++})$
$f_2(1565)$	$0^+(2^{++})$	$\rho_5(2350)$	$1^+(5^{--})$
$h_1(1595)$	$0^-(1^{+-})$	$a_6(2450)$	$1^-(6^{++})$
• $\pi_1(1600)$	$1^-(1^{-+})$	$f_6(2510)$	$0^+(6^{++})$
$a_1(1640)$	$1^-(1^{++})$		
$f_2(1640)$	$0^+(2^{++})$		
• $\eta_2(1645)$	$0^+(2^{-+})$		
• $\omega(1650)$	$0^-(1^{--})$		
• $\omega_3(1670)$	$0^-(3^{--})$		

OTHER LIGHT

Further States

STRANGE ($S = \pm1$, $C = B = 0$)

	$I(J^P)$
• $K^{\pm}$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
$K_0^*(800)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K_0^*(1430)$	$1/2(0^+)$
• $K_2^*(1430)$	$1/2(2^+)$
$K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
$K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K_3^*(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K_0^*(1950)$	$1/2(0^+)$
$K_2^*(1980)$	$1/2(2^+)$
• $K_4^*(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$
$K_3(2320)$	$1/2(3^+)$
$K_5^*(2380)$	$1/2(5^-)$
$K_4(2500)$	$1/2(4^-)$
$K(3100)$	$?^?(?^{??})$

CHARMED ($C = \pm1$)

	$I(J^P)$
• $D^{\pm}$	$1/2(0^-)$
• D^0	$1/2(0^-)$
• $D^*(2007)^0$	$1/2(1^-)$
• $D^*(2010)^{\pm}$	$1/2(1^-)$
• $D_1(2420)^0$	$1/2(1^+)$
$D_1(2420)^{\pm}$	$1/2(?^?)$
• $D_2^*(2460)^0$	$1/2(2^+)$
• $D_2^*(2460)^{\pm}$	$1/2(2^+)$
$D^*(2640)^{\pm}$	$1/2(?^?)$

CHARMED, STRANGE ($C = S = \pm1$)

	$I(J^P)$
• $D_s^{\pm}$	$0(0^-)$
• $D_s^{*\pm}$	$0(?^?)$
• $D_{sJ}^*(2317)^{\pm}$	$0(0^+)$
• $D_{sJ}(2460)^{\pm}$	$0(1^+)$
• $D_{s1}(2536)^{\pm}$	$0(1^+)$
• $D_{s2}(2573)^{\pm}$	$0(?^?)$

BOTTOM ($B = \pm1$)

	$I^G(J^{PC})$
• $B^{\pm}$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^{\pm}/B^0$ ADMIXTURE	
• $B^{\pm}/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
$B_J^*(5732)$	$?(?^?)$

BOTTOM, STRANGE ($B = \pm1$, $S = \mp1$)

• B^0_s	$0(0^-)$
B_s^*	$0(1^-)$
$B_{sJ}^*(5850)$	$?(?^?)$

BOTTOM, CHARMED ($B = C = \pm1$)

• $B_c^{\pm}$	$0(0^-)$

$c\overline{c}$

• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
$h_c(1P)$	$?^?(?^{??})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
$\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$
$\psi(3836)$	$0^-(2^{--})$
$X(3872)$	$?^?(?^?)$
• $\psi(4040)$	$0^-(1^{--})$
• $\psi(4160)$	$0^-(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$

$b\overline{b}$

$\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
• $\Upsilon(2S)$	$0^-(1^{--})$
• $\chi_{b0}(2P)$	$0^+(0^{++})$
• $\chi_{b1}(2P)$	$0^+(1^{++})$
• $\chi_{b2}(2P)$	$0^+(2^{++})$
• $\Upsilon(3S)$	$0^-(1^{--})$
• $\Upsilon(4S)$	$0^-(1^{--})$
• $\Upsilon(10860)$	$0^-(1^{--})$
• $\Upsilon(11020)$	$0^-(1^{--})$

NON-$q\overline{q}$ CANDIDATES

NON-$q\overline{q}$ CANDIDATES

For me only

Review of hadrons = strongly interacting

		m (MeV)	J	I	decay	τ	
mesons ($A=0$)	$\pi^\pm$	140	0	1	$\pi^- \to \mu^- \bar{\nu}_\mu$	2.6×10^{-8} s	(weak)
	π^0	135			$\pi^0 \to \gamma\gamma$	8.4×10^{-17} s	(emc)
(refer PDG)	η	548	0	0 ↑ (talk about)	$\eta \to \gamma\gamma$ [39] $\to \pi\pi\pi$ [55]	5×10^{-19} s [$\Gamma = 1.29$ keV]	(strong + emc)
	η'	958	0	0	$\eta' \to \pi\pi\eta$ [44] $\rho\gamma$ [29]	3×10^{-21} s [$\Gamma = 0.2$ MeV]	
	$\rho^\pm$, ρ^0	775	1	1	$\rho \to \pi\pi$	4×10^{-24} s	(strong)
	ω	782	1	0	$\omega \to \pi^+\pi^-\pi^0$ [89]	8×10^{-23}	(strong)
	ϕ	1020	1	0	[$\pi^+\pi^-$ 2%] $\phi \to K^+K^-$ [49] $K^0\bar{K}^0$ [34] $\pi^+\pi^-\pi^0$ [15]	1.5×10^{-22}	
baryons ($A=1$)	$N^+ = p$	938.3	$\frac{1}{2}$	$\frac{1}{2}$	stable		
	$N^0 = n$	939.6			$n \to p e^- \bar{\nu}_e$	15 min	
	Δ	1230	$\frac{3}{2}$	$\frac{3}{2}$	$\Delta \to N\pi$ (BR from isospin)	5×10^{-24} s	(strong)
mesons	K^0	498	0	$\frac{1}{2}$	$K^0 \to \pi^+\pi^-$ [69] $\pi^0\pi^0$ [31]	0.9×10^{-10} s	
	K^+	494			$K^+ \to \mu^+\nu_\mu$ [63] $\pi^+\pi^0$ [21] Q = 218 MeV $\pi^+\pi^+\pi^-$ [5] Q = 73 MeV	1.2×10^{-8} s	
	K^{0*}	892	1	$\frac{1}{2}$			
	K^{+*}	896			$K^* \to K\pi$	1.3×10^{-23}	
baryons	Λ^0	1116	$\frac{1}{2}$	0	$\Lambda^0 \to p\pi^-$ [64] $n\pi^0$ [36]	2.6×10^{-10} s	(8 cm)
	Σ^+	1189	$\frac{1}{2}$	1	$\Sigma^+ \to p\pi^0$ [52] $n\pi^+$ [48]	0.8×10^{-10} s	
	Σ^0	1193			$\Sigma^0 \to \Lambda\gamma$	7×10^{-20} s	(emc)
	Σ^-	1197			$\Sigma^- \to n\pi^-$	1.5×10^{-10} s	
	Ξ^-	1315	$\frac{1}{2}$	$\frac{1}{2}$	$\Xi^0 \to \Lambda\pi^0$	3×10^{-10} s	
	Ξ^0	1321			$\Xi^- \to \Lambda\pi^-$	1.6×10^{-10} s	
	Σ^*	1385	$3/2$	1	$\Sigma^* \to \Lambda\pi, \Sigma\pi$	2×10^{-23} s	
	Ξ^*	1530	$3/2$	$1/2$	$\Xi^* \to \Xi\pi$	7×10^{-23} s	

Iso-triplet mesons (?) ... I ... π 135 ... 0 ... -1, 0, 1
ρ 775 ... 1 ... -1, 0, 1

(background)

Isosinglet mesons (I = 0, A = 0)

[For my info]

	mc^2	J	Q	τ	decay
η	550 MeV	0	0	5E-19 s	γγ (39%) $\pi^0\pi^0\pi^0$ (30%) $\pi^0\pi^+\pi^-$ (22%) (ππ violates P, CP)
η'	960	0	0	3E-21 s	$\pi^+\pi^-\eta$ (44%) $\pi^0\pi^0\eta$ (21%) (ππ violates P, CP)
ω	780	1	0	E-22 s	$\pi^+\pi^-\pi^0$ ($\pi^0\pi^0\pi^0$ violates C) $\pi^+\pi^-$ small
φ	1020	1	0	E-22 s	KK

So far, avg electric charge of meson multiplets is zero.

I_3			
1	π^+	ρ^+	
0	π^0	ρ^0	η η' ω φ
-1	π^-	ρ^-	

$\Rightarrow Q = I_3$ for mesons

[not true for p, n!]

for p, n: $Q = I_3 + \frac{1}{2}$

Decays

K^0, K^+ lightest charge mesons

decay **must** violate strangeness

$K \to \pi\pi$

$K^0 \to \pi^+\pi^-$ (Dec 1947) Rochester Butler
$K^+ \to \pi^+\pi^-\pi^-$ (1949) Powell

[
$K^0 \to \pi\pi$ 10^{-10} sec

$K^+ \to \pi\pi$ 10^{-8} sec
$\pi\pi\pi$
$\mu^+\nu_\mu$

$K^0 \to \gamma\gamma$ } so emc conserves strange ??
$K^+ \to \pi^+\gamma$
]

Λ^0 lightest strange baryon

$\Lambda^0 \not\to n\bar{K}^0$ conserves A, S but not energy

$\Lambda^0 \to p\pi^-$ violates S (weak)
$ n\pi^0$

[$\tau = 10^{-10}$ s]

$\Lambda^0 \to p\pi^-, n\pi^0$ (1950) Anderson

Σ^+

$\Sigma^+ \not\to \Lambda^0\pi^+$ conserve A, S but not energy

[$\tau = 10^{-10}$ s]

$\Sigma^+ \to n\pi^+$ weak

$\Sigma \to p\pi^0, p\pi^+$ (1952) BNL Cosmotron

Σ^0

$\Sigma^0 \not\to \Lambda^0\pi^0$ violate energy

$\Sigma^0 \to \Lambda^0\gamma$ conserve A, S, energy

↑ electromagnetic interaction [$\tau = 10^{-19}$ s]