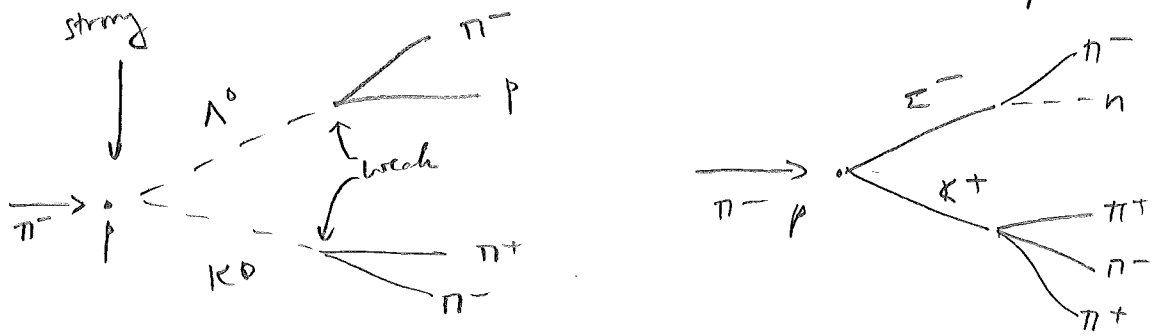
Strange particles

[About 1950, new particles found that behaved wrong]

- produced strongly (i.e. w/ typical strong interaction $\sigma \sim 1$ mb)
- decay weakly (i.e. w/ typical weak interaction $\tau \sim 10^{-10}$ s $\Rightarrow c\tau = 3$ cm) tracks!

[show photo →]



Even though $\Lambda^0 \to p\pi^-$ only involves hadrons, it is a weak interaction because τ is so long ($\tau \gg 10^{-23}$ s)

	I_3	m	J	A	$Q - I_3 - \frac{1}{2}A$
K^+	$\frac{1}{2}$	~495 MeV	0	0	$\frac{1}{2}$
K^0	$-\frac{1}{2}$				
Λ^0	0	~1115 MeV	$\frac{1}{2}$	1	$-\frac{1}{2}$
Σ^+	+1	~1190 MeV	$\frac{1}{2}$	1	$-\frac{1}{2}$
Σ^0	0				
Σ^-	−1				

[
Dec 47: $K^0 \to \pi^+\pi^-$ Rochester Butler (cosmic)
49 $K^+ \to \pi^+\pi^+\pi^-$ Powell
50 $\Lambda^0 \to p\pi^-$ Anderson
52 Σ BNL cosmotron
]

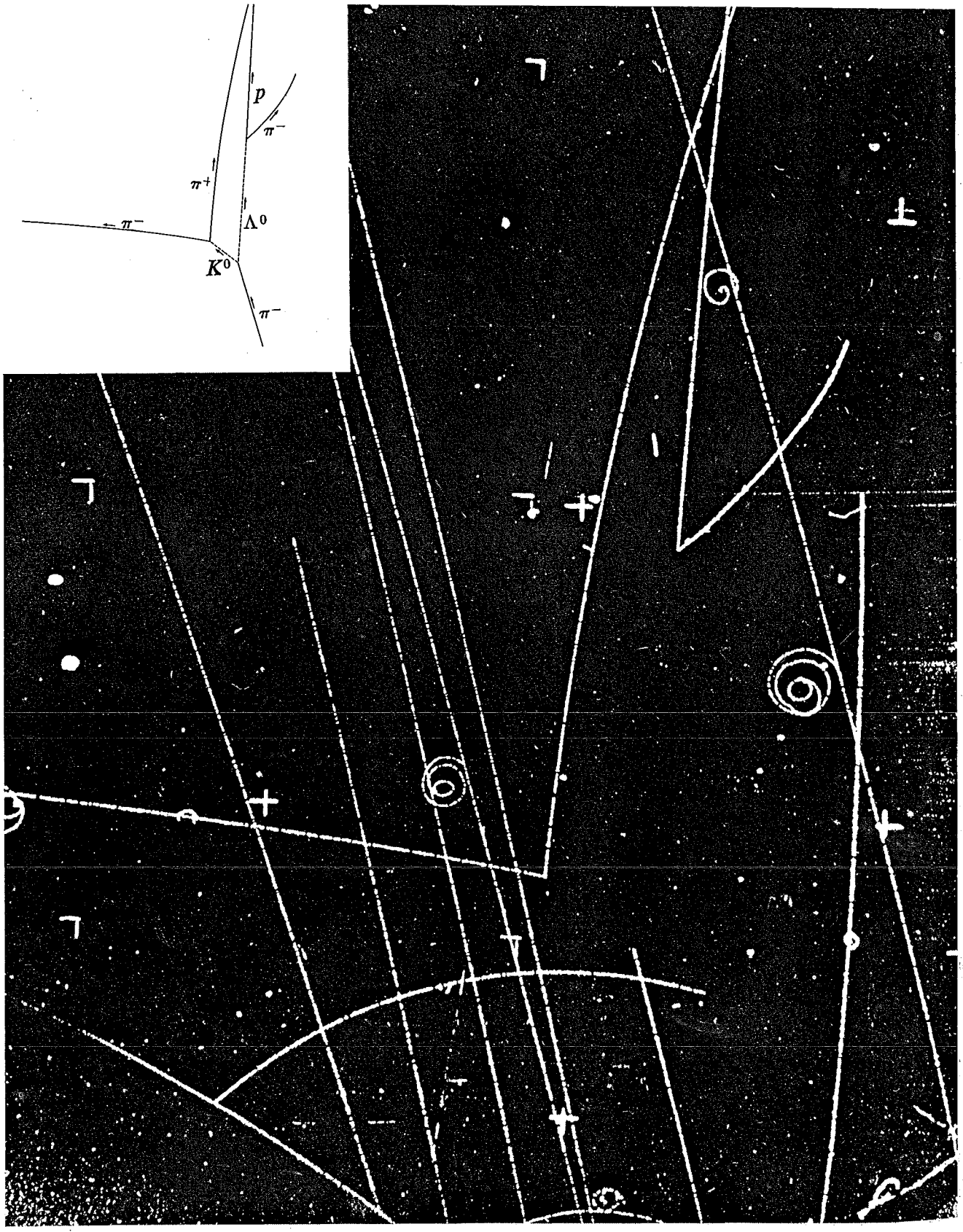


Figure 15-3 Bubble-chamber picture showing the following reactions:

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

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

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

[Courtesy Lawrence Radiation Laboratory, Berkeley, Calif.]

in Segrè

Associated production: Strange particle always produced in pairs

1953 Gell-Mann, Nishijima: new quantum no. S ("strangeness")

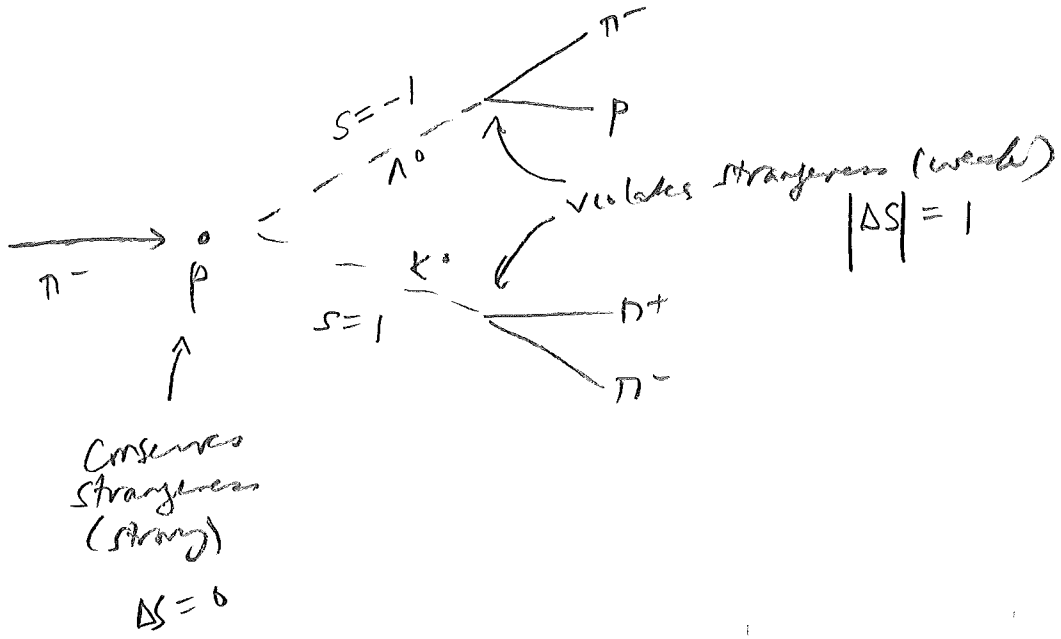
conserved by strong and electromagnetic interactions

violated by weak interactions

	S
$K^+ K^0$	1
Λ^0	−1
$\Sigma^+ \Sigma^0 \Sigma^-$	−1

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

Gell-Mann Nishijima relation



Decays

K^0, K^+ lightest strange mesons

decay must violate strangeness

$K \to \pi\pi$

- $K^0 \to \pi\pi$ 10^{-10} sec
- $K^+ \to \pi\pi$, $\pi\pi\pi$, $\mu^+\nu_\mu$ 10^{-8} sec
- $K^0 \to \gamma\gamma$, $K^+ \to \pi^+\gamma$ } so emc conserves strangeness

Λ^0 lightest strange baryon

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

$\Lambda^0 \to \begin{cases} p\,\pi^- \\ n\,\pi^0 \end{cases}$ violates S (weak)

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

Σ^+

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

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

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

Σ^0

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

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

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

$$Q = I_3 + \tfrac{1}{2}A + \tfrac{1}{2}S$$

weak interactions violate S and $\therefore$ also I_3, I

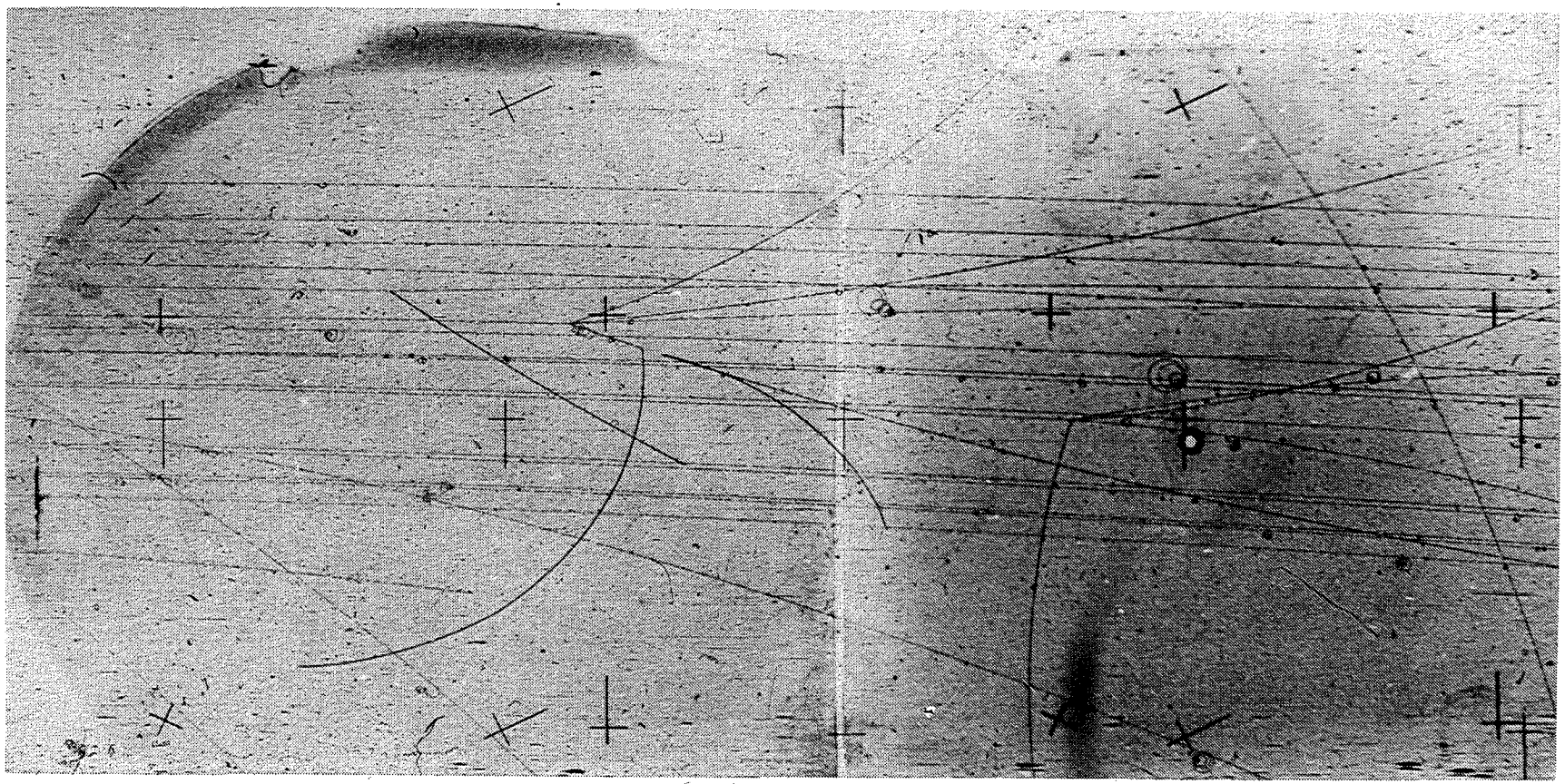
eg.	Λ^0	$\rightarrow$	$p\ \pi^-$
I_3	0		$\frac{1}{2}\ -1$

emc interactions conserve S + $\therefore$ also I_3

however violate I

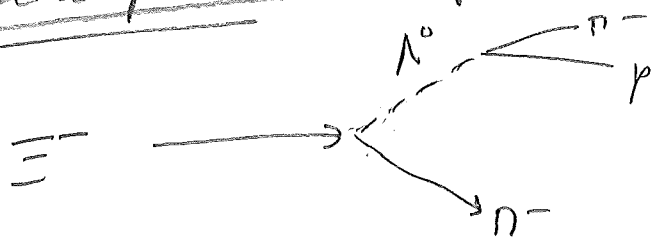
	Σ^0	$\rightarrow$	$\Lambda\ \gamma$
I_3	0		0 0
			0 0
I	1		

Fig. 5.6. An example of Ξ^--production and decay in the British 1.5 m bubble chamber exposed to a 6 GeV/c K^--beam from the CERN proton synchrotron. The Ξ^- emerges as the lowest of four tracks from the interaction in the left-hand half of the picture and rapidly decays to a Λ and a π^-.



[Even stranger]

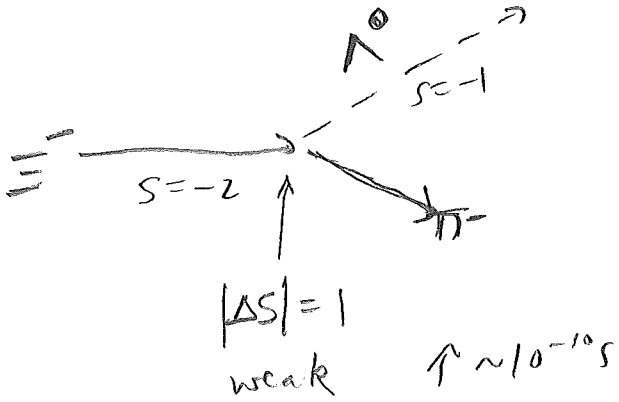
Cascade particles: decay weakly into strange particles



[See photo]

	I_3	m	I	A	$Q - I_3 - \frac{1}{2}A$	S
Ξ^0	$\frac{1}{2}$	1320 MeV	$\frac{1}{2}$	1	−1	−2
Ξ^-	$-\frac{1}{2}$					

doubly strange



[$\Xi^- \to \Sigma^- \pi^0$ violates energy (mass)]

Summary

Scalar ($J=0$) mesons	mass (MeV)	S
$\pi^+ \pi^0 \pi^-$	140	0
η	550	0
η'	960	0
$K^+ K^0$	495	1
$\bar{K}^0 K^-$	495	−1

vector ($J=1$) mesons		
$\rho^+ \rho^0 \rho^-$	770	0
ω	780	0
ϕ	1020	0
new → $K^{+*} K^{0*}$	890	1
new → $\bar{K}^{0*} K^{-*}$	890	−1

$J=\frac{1}{2}$ baryons		
p n	940	0
Λ^0	1115	−1
$\Sigma^+ \Sigma^0 \Sigma^-$	1190	−1
$\Xi^0 \Xi^-$	1320	−2

$J=\frac{3}{2}$ baryons		
$\Delta^{++} \Delta^+ \Delta^0 \Delta^-$	1230	0
new → $\Sigma^{+*} \Sigma^{0*} \Sigma^{-*}$	1385	−1
new → $\Xi^{0*} \Xi^{-*}$	1530	−2

HW ↓

$K^* \to K\pi$
$\Sigma^* \to \Lambda\pi, \Sigma\pi$
$\Xi^* \to \Xi\pi$
do not violate $S_1 \Rightarrow \tau \sim 10^{-23}$ s

[quite atomic $\sim 10{,}000$ fm]

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)

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 momentum (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 + (4) + 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.

See also the table of suggested $q\bar{q}$ 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 ($S = C \neq B = 0$)

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

OTHER LIGHT

Further States

STRANGE ($S = \pm 1$, $C = B = 0$)

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

CHARMED ($C = \pm 1$)

• $D^{\pm}$	$1/2(0^-)$
• 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 ($C = S = \pm 1$)

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

BOTTOM ($B = \pm 1$)

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

BOTTOM, STRANGE ($B = \pm 1$, $S = \mp 1$)

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

BOTTOM, CHARMED ($B = C = \pm 1$)

• $B_c^{\pm}$	$0(0^-)$

$c\bar{c}$

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

$b\bar{b}$

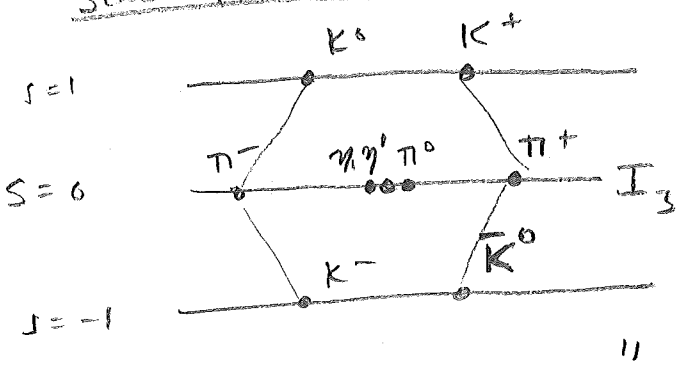
$\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
• $\Upsilon(2S)$	$0^-(1^{--})$
• $\chi_{b0}(2P)$	$0^+(0^{++})$
• $\chi_{b1}(2P)$	$0^+(1^{++})$
• $\chi_{b2}(2P)$	$0^+(2^{++})$
• $\Upsilon(3S)$	$0^-(1^{--})$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

NON-$q\bar{q}$ CANDIDATES

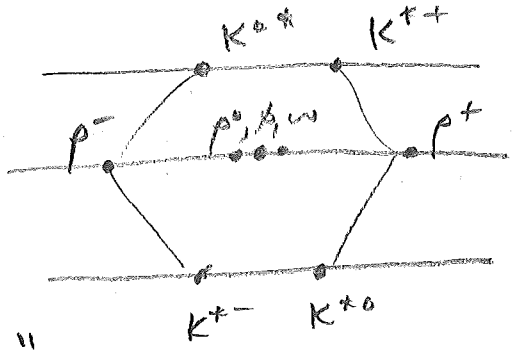
NON-$q\bar{q}$ CANDIDATES

Supermultiplets

Scalar mesons

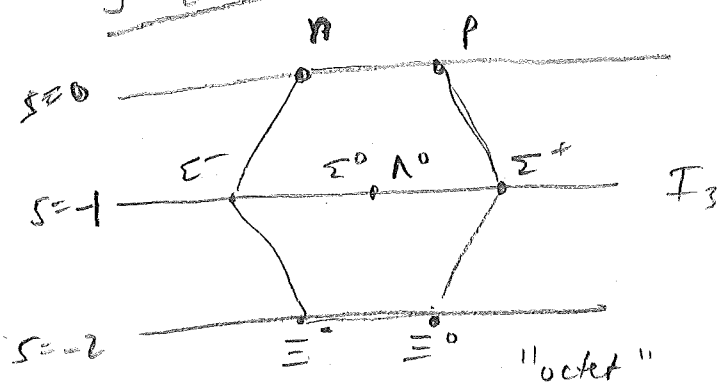


vector mesons



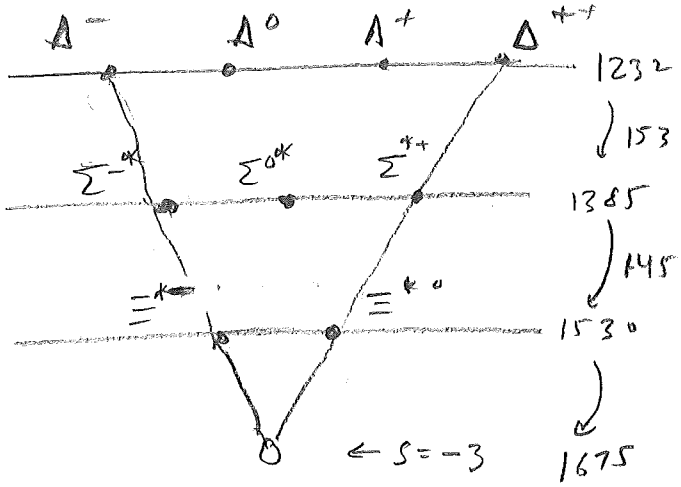
"nonets"

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



"octet"

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



1961 Gell-Mann recognized these as weight diagrams of SU(3) w/ one particle missing

Predicted Ω w/ $J = \frac{3}{2}$, $I = I_3 = 0$, $S = -3$, $m \sim 1675$ MeV

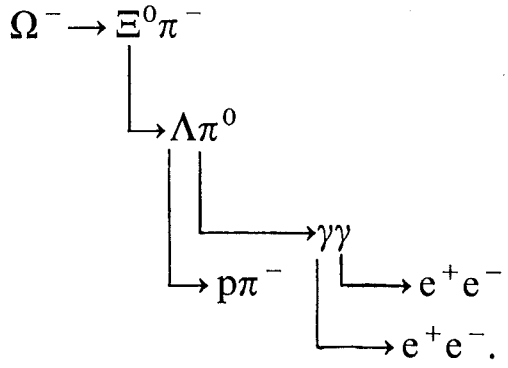
$$Q = I_3 + \tfrac{1}{2}(A + S) = 0 + \tfrac{1}{2}(1 - 3) = -1$$

weak decay into $\Omega^- \longrightarrow \Xi^0 \pi^-$

Ω^- discovered at BNL in 1964

w/ $m = 1672$ MeV

[⇒ photo]



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 $\frac{3}{2}$.

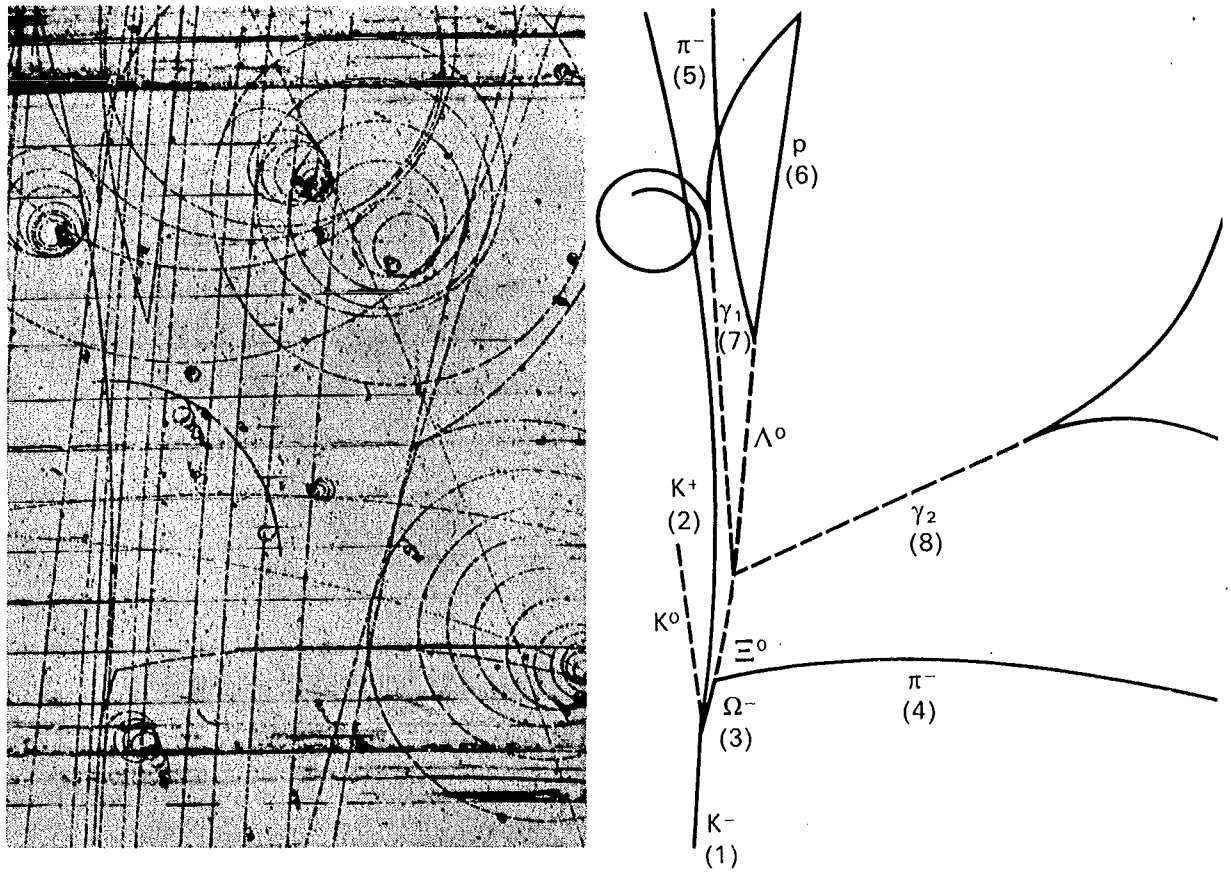


Fig. 5.8. The first Ω^--particle to be observed (Brookhaven National Laboratory, 1964).