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]

$$\pi^- p \xrightarrow{\text{strong}} \Lambda^0 \xrightarrow{\text{weak}} p\pi^-$$
$$\qquad\qquad\quad K^0 \xrightarrow{\text{weak}} \pi^+\pi^-$$

[copied in problem]

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

1953 Gell Mann, Nishijima independently explained this 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 $\neq 0$)

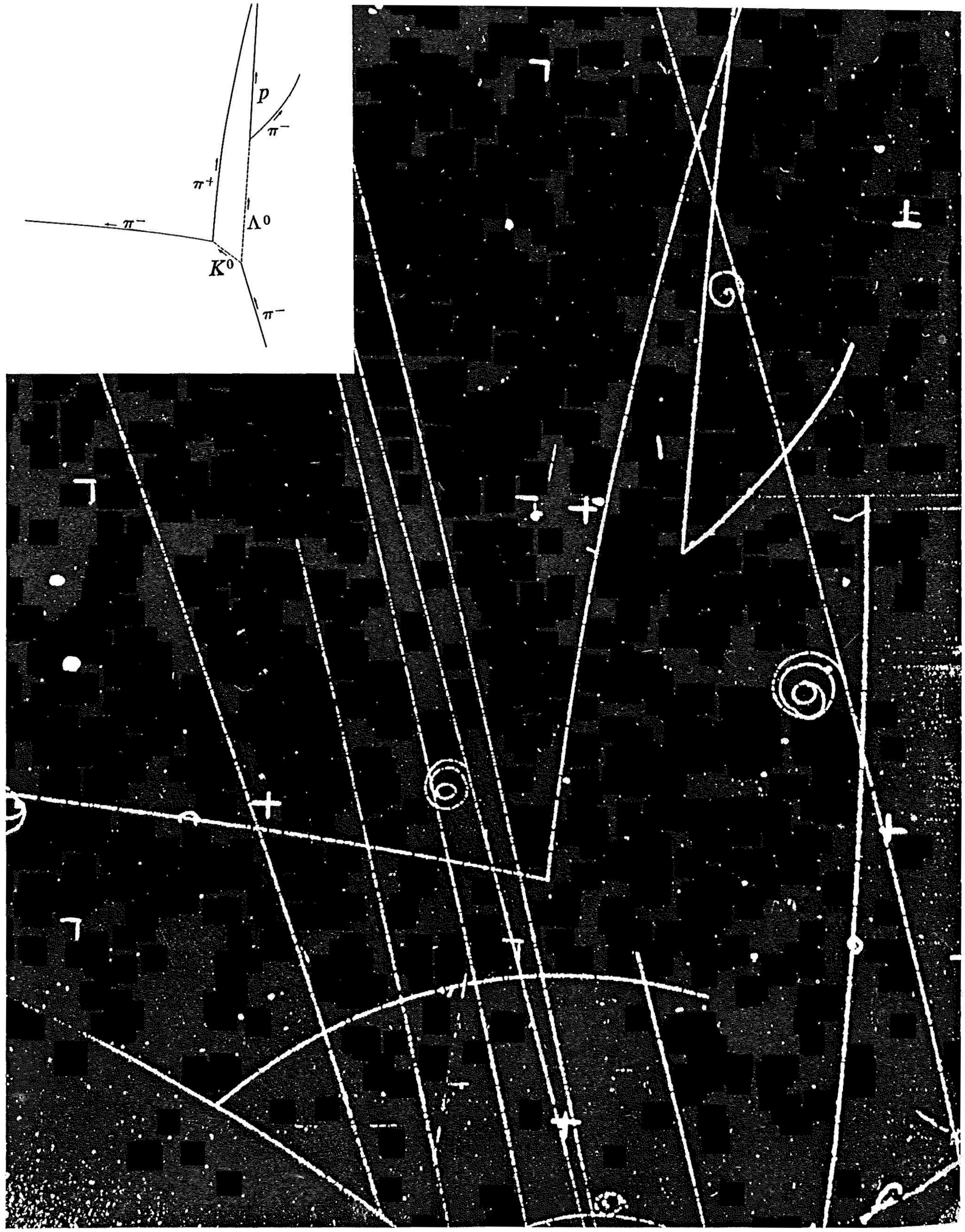


Figure 15-3 Bubble-chamber picture showing the following reactions:

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

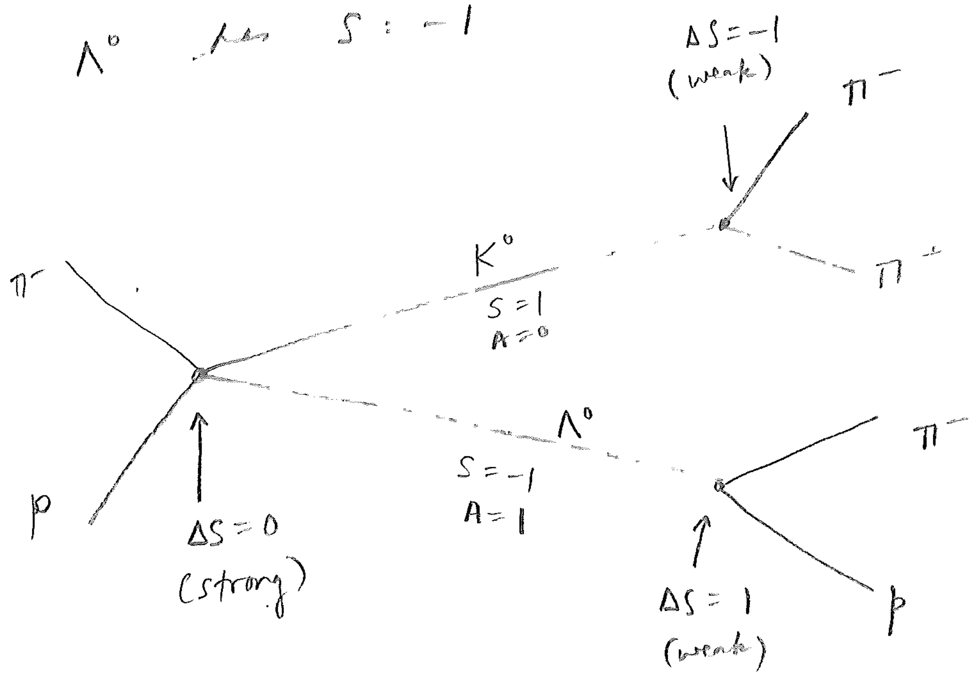
[Courtesy Lawrence Radiation Laboratory, Berkeley, Calif.]

in Segre

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 ∴ 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

$S=-1$, $A=1$ → $A=1$, $S=-1$

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

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

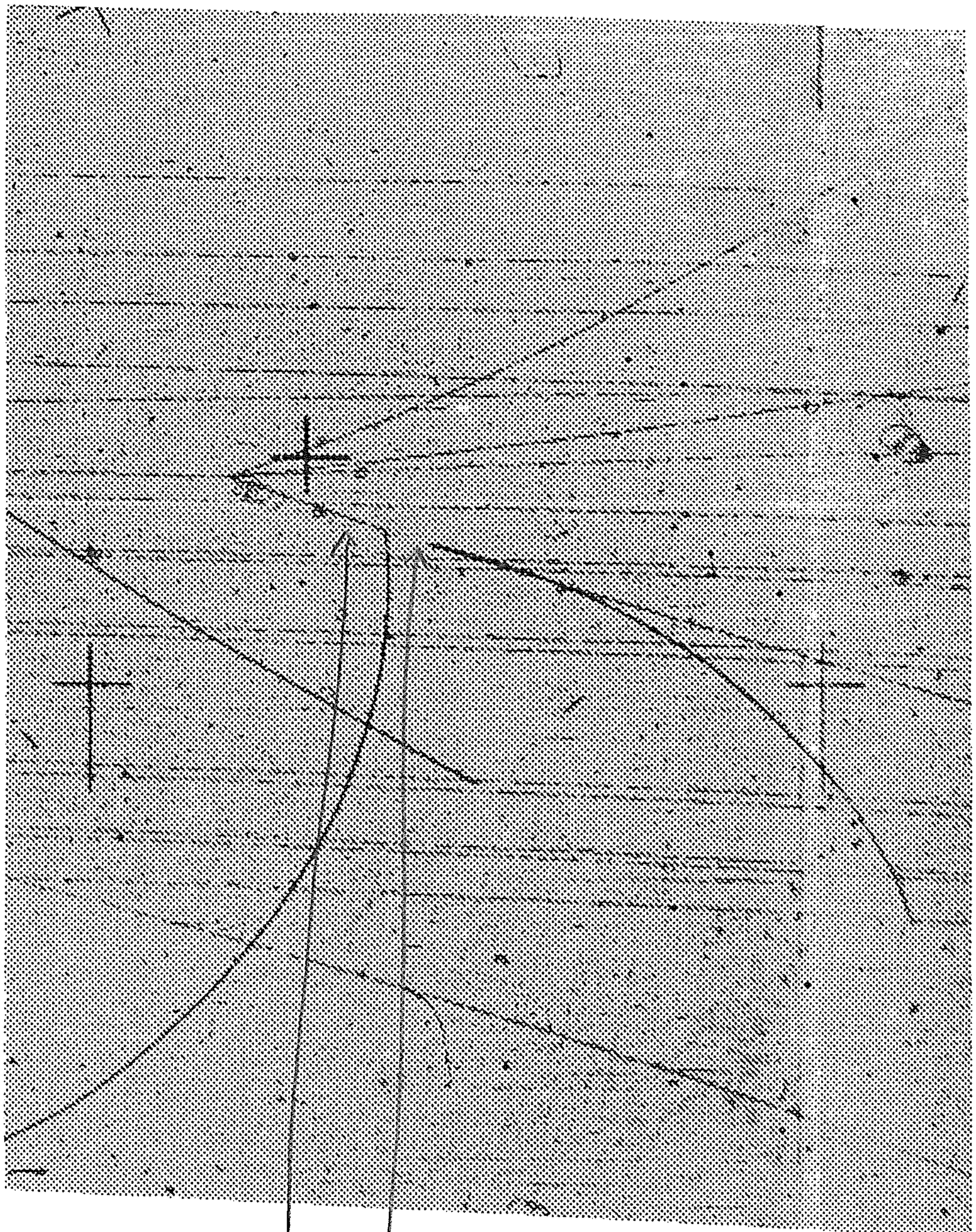
$N\pi$ is tensor product $\underset{\sim}{2} \otimes \underset{\sim}{3} = \underset{\sim}{4} \oplus \underset{\sim}{2}$

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)



strange

$\Xi^- \to \pi \Lambda^0$

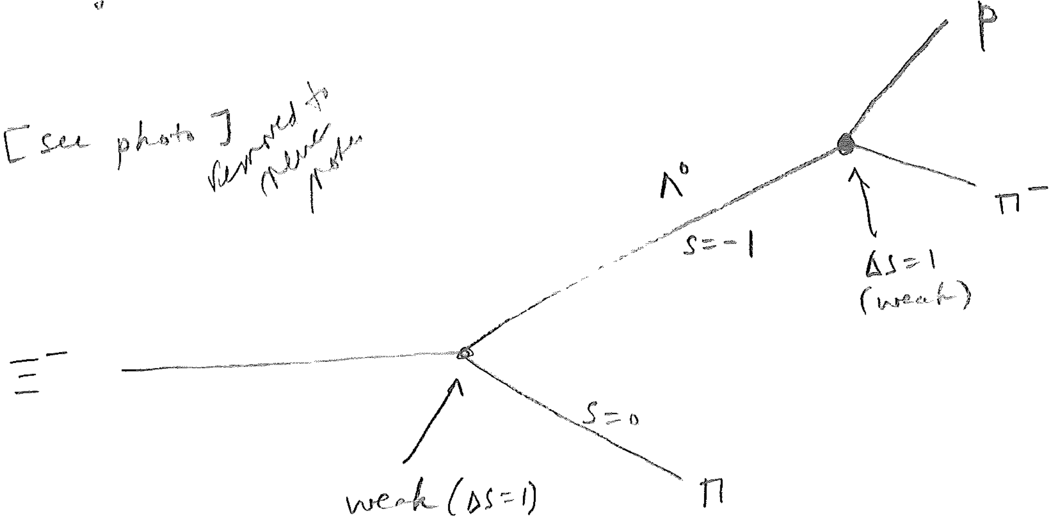
$\Lambda^0 \to p\pi$

$\xrightarrow{?} \Xi^- K^+ X$

Cascade particles

decays weakly into strange particles

[see photo] removed to reduce pages



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

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

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

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

$$-1 = I_3 + \tfrac{1}{2} + \tfrac{1}{2}(-2) \quad \Rightarrow \quad I_3 = -\tfrac{1}{2}$$

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 ($\Xi^* \to \Xi \pi$)

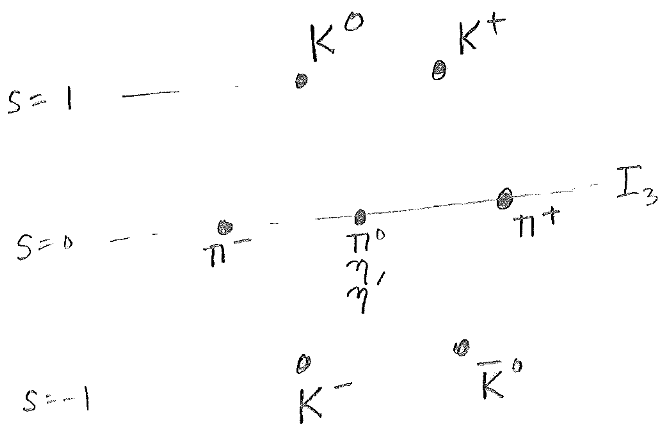
The finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be punished by a 10,000 dollar fine.

–Willis Lamb (1955)

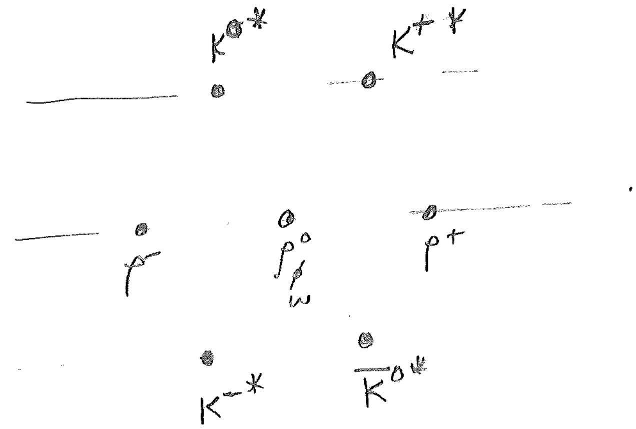
All hadrons belong to isospin multiplets, i.e. representations of SU(2) which are approximately degenerate

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

Scalar (J = 0) mesons

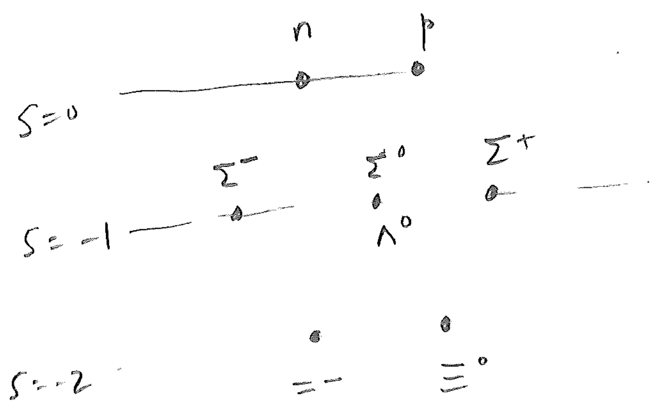


vector (J = 1) mesons

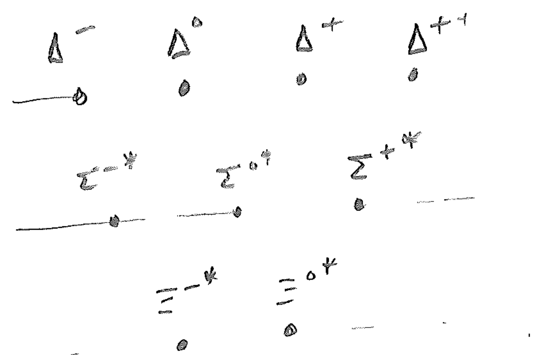


meson "nonets"

J = ½ baryons



J = 3/2 baryons



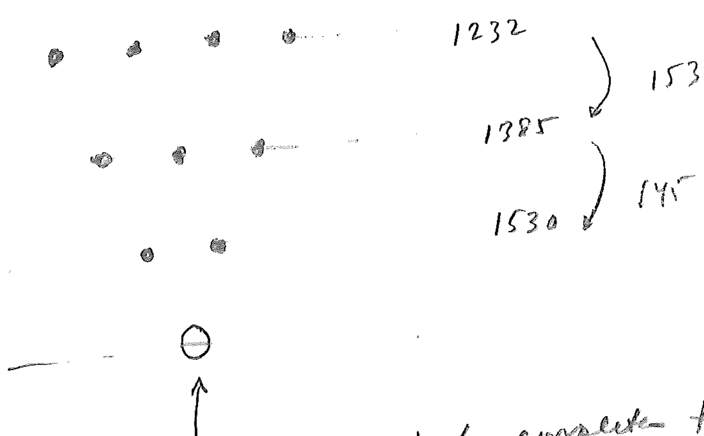
baryon "octet"

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

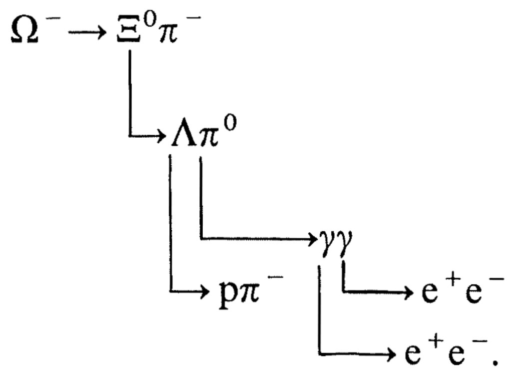
∴ it would decay weakly $\Omega^- \xrightarrow[\Delta S = 1]{} \Xi^0 \pi^-$

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

1964 discovered BNL w/ $m = 1672$ 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

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

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 $\frac{3}{2}$.

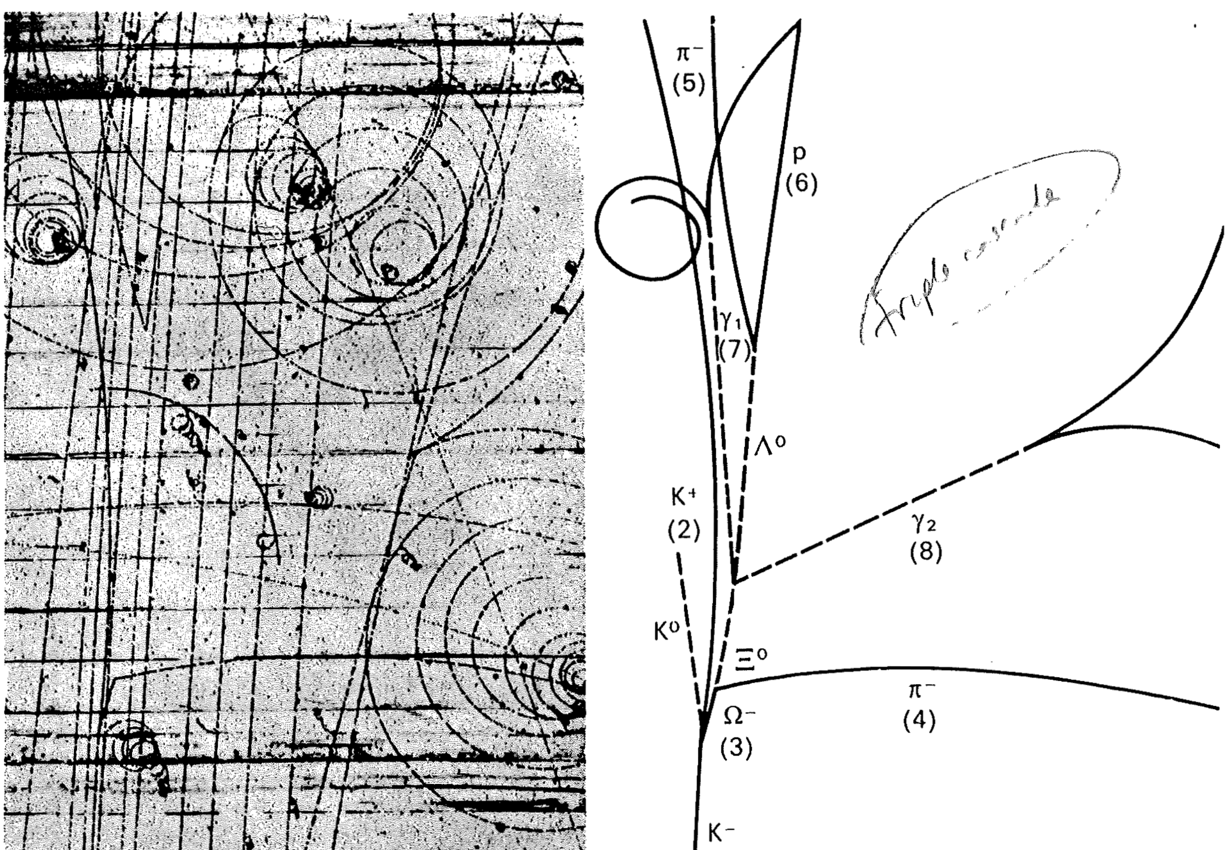


Fig. 5.8. The first Ω^--particle to be observed (Brookhaven National Laboratory, 1964).