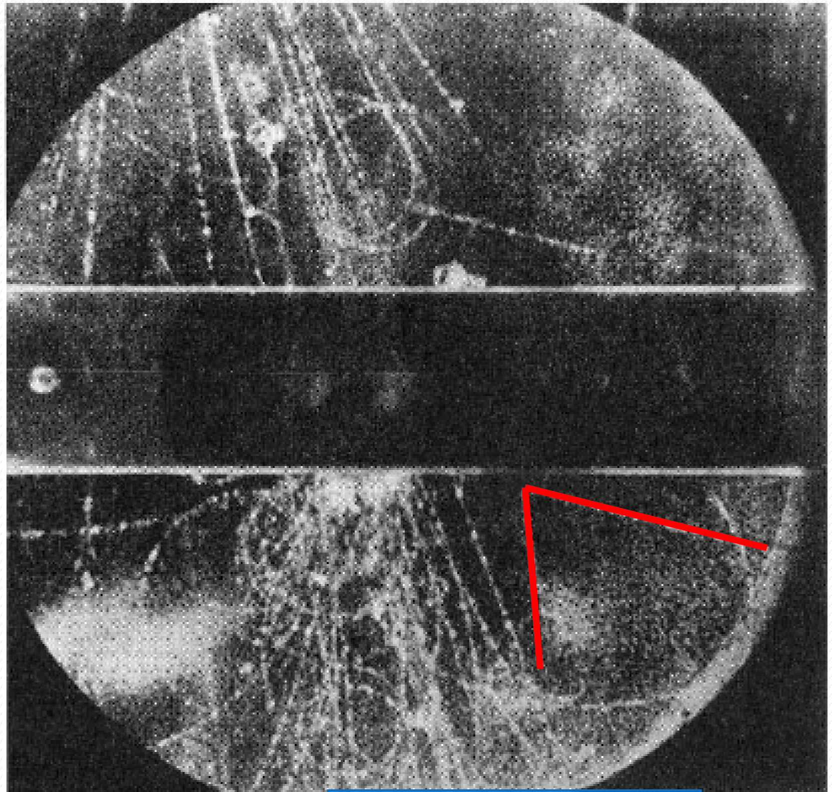
- Discovery of "Strange" particles
- A new quantum number: strangeness
- isospin and strangeness
- The particle zoo
- SU(3)

Discovery of the strange particles

The first pioneering study on “strange” particle have been done by using cloud chamber experiments realized at see level and in high moutaign, and by using nuclear emulsion in aerostatic ballons.

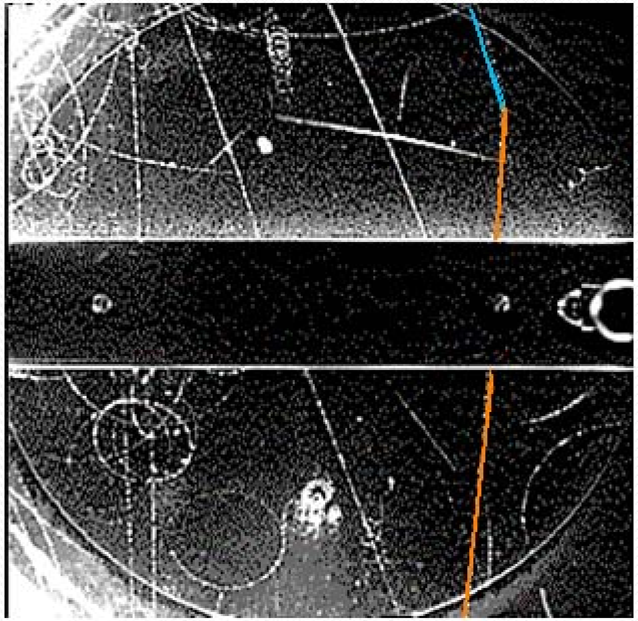


$$K^0 \rightarrow \pi^- \pi^+$$

- 1943 Leprince-Ringuet: find a new particle of massa 506±61MeV.
- 1947 Rochester e Butler identiify very clear V neutral partcle during 1-year data taking with a cloud chamber at sea-level.

The discovery of "strange" particles

In addition to the neutral strange V particles also charged strange particles which decay into a charge particle [+ neutral] (θ) or in 3 charged (τ) particles where discovered.

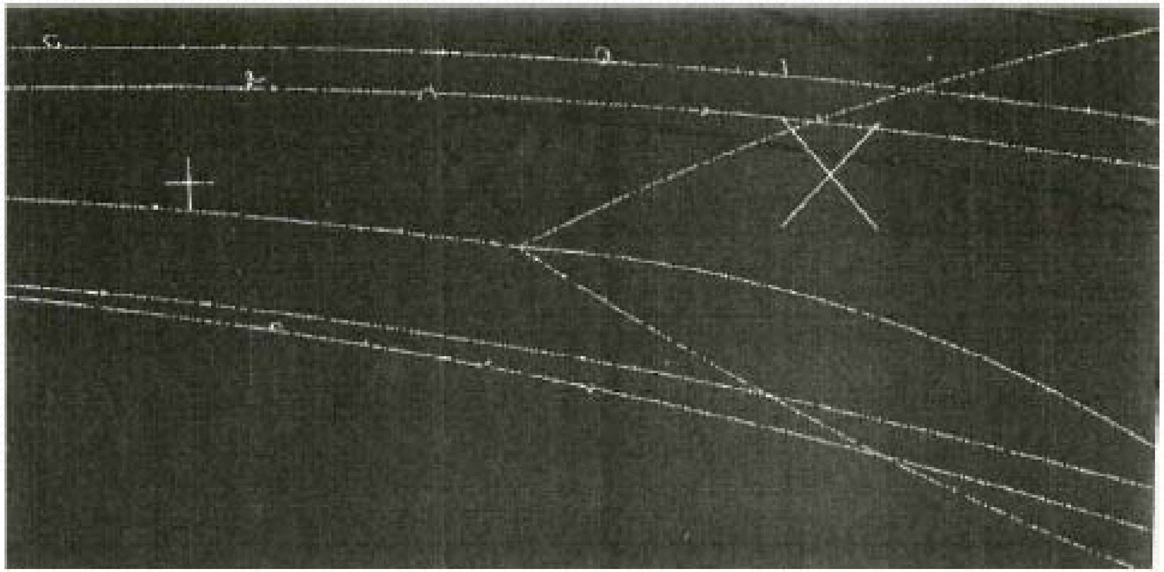


$$K^+ \to \mu^+ \nu$$

- asociate production:

  in 1947 it became clear that the new particles were produced in pairs, one with a mass about 500 MeV (K) and the other with a mass larger than the nucleon (hyperon)
- The hyperon did deay into nucleon + pion

3 charged K decays



$$K^+\left[\tau^+\right]\to\pi^+ + \pi^+ + \pi^-$$

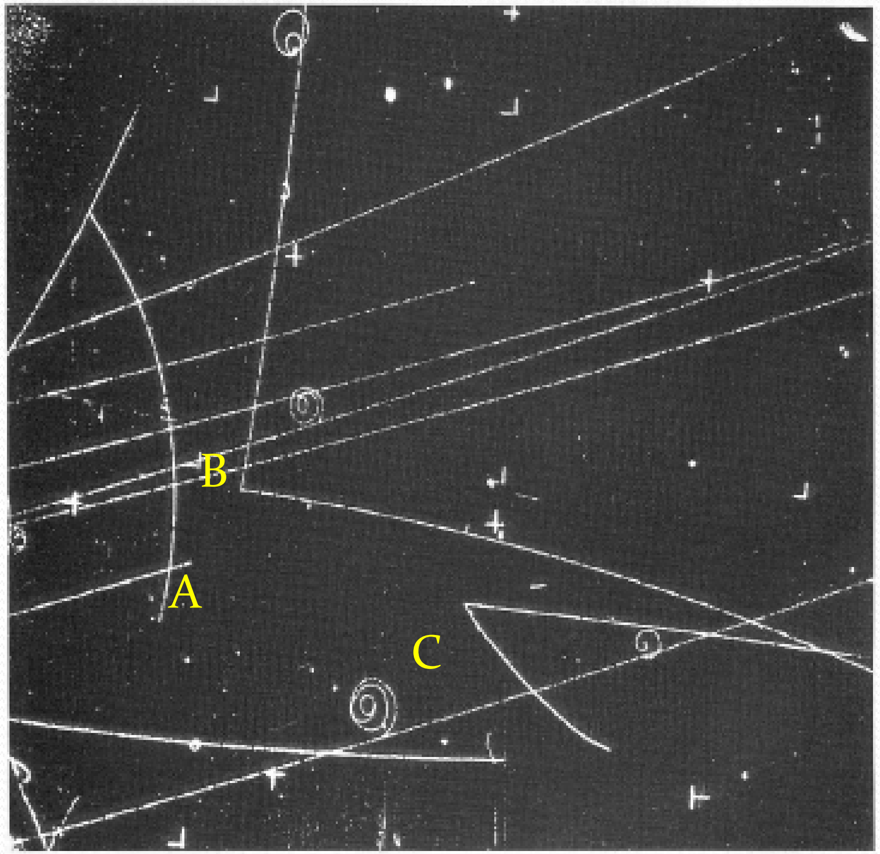
Inoltre:

B.R.$\left(K^+\to\mu^+ + \nu\right)$=63.5% ; B.R.$\left(K_s^0\to\mu^+ + \mu^-\right)$<$3.2\cdot10^{-7}$

Effetto GIM

Associated production: $\pi^- + p \rightarrow \Lambda + K$

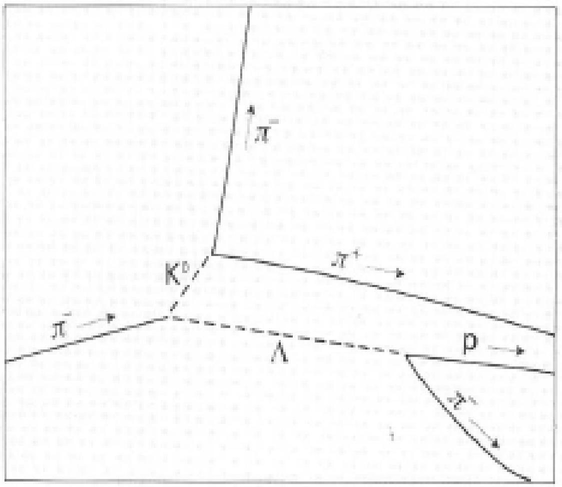
1 GeV/c π^- in a liquid-H bubble chamber



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

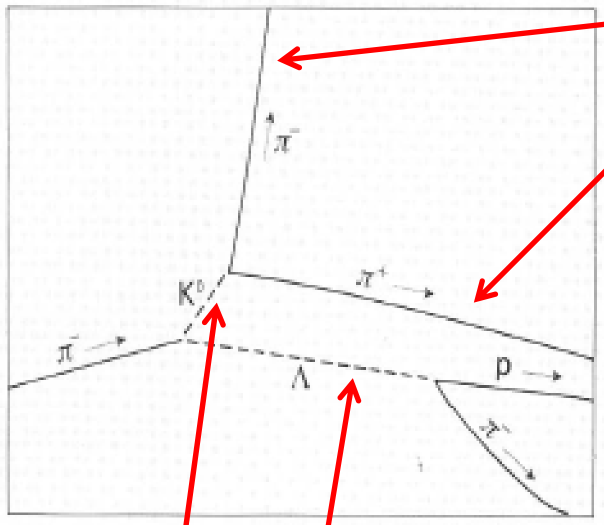
B) $K^0 \rightarrow \pi^- + \pi^+$

C) $\Lambda \rightarrow p + \pi^-$



N.B. : why K° and not anti-K°?

Mass and lifetime measurement



from the curvature we infer the momentum of the particle and by knowing its mass also the energy/

Then the invariant mass of the mother particle can be extracted

$$m_K = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

From the mass and energy (E1+E2) the γ factor can be determined and hence β.

$$\gamma = \frac{E}{m}$$

From the average decay lenght λ we finally get the τ

$$\lambda = \gamma\beta c\tau$$

Why strange?

- The production cross-section of these particle is of the order of mb, which is typical of strong interactions
- Lifetimes are of the order of 10^{-10} s, which is typical of week interaction (int. e.m. ~ 10^{-20} s, strong int.~ 10^{-23}s)

1. Why $\Lambda \rightarrow p + \pi^-$ does not proceed through strong interaction?
2. Why are these particles produced in pairs?

3. (i n a d d i t i o n τ-θ puzzle: same mass and lifetime but opposite parity

Strangeness

- In 1954 an explanation for these anomalies was provided by Gell--Mann and Pais and independently by Nishijima.

  They introduced a new quantum number strangness, which is conserved in strong interaction but it is not in weak interactions

- Strangness is an additive quantum number. The “old” hadrons, nucleons and pions, have S = 0 while hyperons have S=-1 and K mesons have S=±1.

- In the production the strange particles should be produced in pairs (associated production) with opposite strangeness

Associated production examples

$$\pi^- + p \to K^0 + \Lambda \quad ; \quad \pi^- + p \to K^0 + K^- + p$$

$$\pi^+ + n \to K^+ + \Lambda \quad ; \quad \pi^+ + n \to K^+ + K^- + p$$

$$\pi^- + p \to K^0 + \Sigma^0 \quad ; \quad \pi^- + p \to K^+ + \Sigma^-$$

$$\pi^+ + n \to K^+ + \Sigma^0 \quad ; \quad \pi^+ + n \to K^0 + \Sigma^+$$

$$\pi^+ + p \to K^+ + \Sigma^+$$

m($\pi^\pm$) = 139.6 MeV ; m(p) = 938.3 MeV ; m(n) = 939.6 MeV

m($K^\pm$) = 493.68 MeV ; m(K^0) = 497.67 MeV

m(Λ) = 1115.7 MeV

m($\Sigma^\pm$) = 1189.4 MeV ; m(Σ^0) = 1192.6 MeV

m(Ξ^0) = 1314.8 MeV ; m(Ξ^{-1}) = 1321.3 MeV

why anti-hyperons are not produced?

Strangeness of the K mesons

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

$\pi^+ + n \to K^+ + \Lambda$; $\pi^+ + n \to K^+ + K^- + p$

Inoltre non si osserva la reazione: $\pi^- + n \to K^- + \Lambda$

K^0, Λ : opposite strangenes

K^0, K^- : opposite strangeness

Λ, K^- : same strangeness

K^+, Λ : opposite strangenes

K^+, K^-: opposite strangeness

$\bar{K}^0, K^-$: same strangeness

K^0, Σ : opposite strangeness

N.B. : for symmetry reason it should exist anti-K°

Isospin and strangeness of K and Λ

$$Q = I_3 + \frac{1}{2}(B+S)$$ ⇒ isospin

$Q(\Lambda)= 0$, $B(\Lambda)=1$, $S(\Lambda)=-1$ $\Rightarrow$ $I_3(\Lambda)= 0$

$Q(K^0)= 0$, $B(K^0)=0$, $S(K^0)=1$ $\Rightarrow$ $I_3(K^0)= -\frac{1}{2}$

$Q(K^+)= 1$, $B(K^+)=0$, $S(K^+)=1$ $\Rightarrow$ $I_3(K^+)= \frac{1}{2}$

$\Rightarrow I=\frac{1}{2}$

$Q(K^-)= -1$, $B(K^-)=0$, $S(K^-)=-1$ $\Rightarrow$ $I_3(K^-)= -\frac{1}{2}$

$Q(\bar{K}^0)= 0$, $B(\bar{K}^0)=0$, $S(\bar{K}^0)=-1$ $\Rightarrow$ $I_3(\bar{K}^0)= \frac{1}{2}$

$\Rightarrow I=\frac{1}{2}$

N.B. : anti-K^0 complete the isospin doublet

Isospin and strangeness of Σ and Ξ

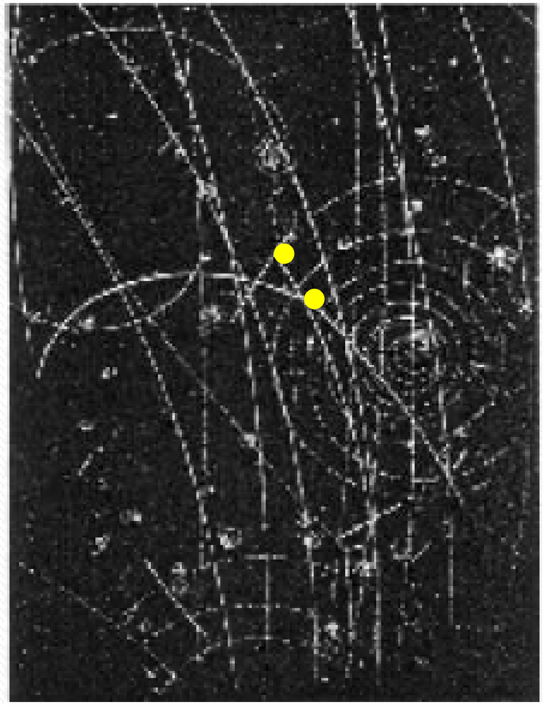
$$Q = I_3 + \frac{1}{2}(B+S)$$ ⇒ isospin

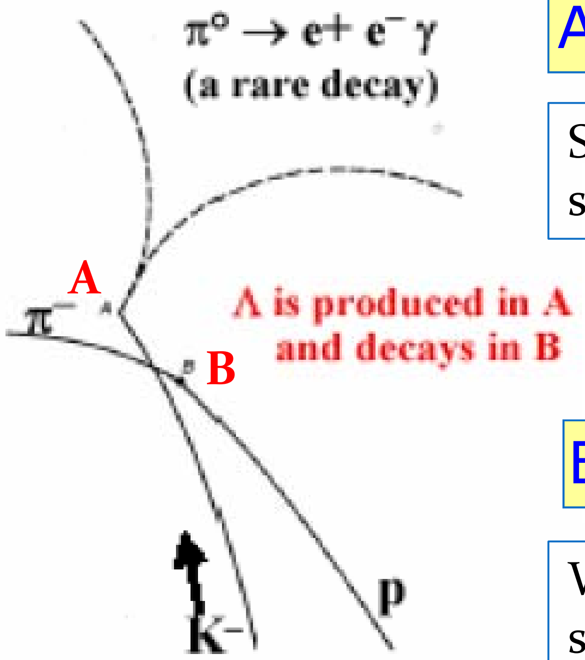
$$\left.\begin{array}{ll} Q(\Sigma^+)= 1 , B(\Sigma^+)=1 , S(\Sigma^+)=-1 & \Rightarrow I_3(\Sigma^+)= 1 \\ Q(\Sigma^0)= 0 , B(\Sigma^0)=1 , S(\Sigma^0)=-1 & \Rightarrow I_3(\Sigma^0)= 0 \\ Q(\Sigma^-)= -1 , B(\Sigma^-)=1 , S(\Sigma^-)=-1 & \Rightarrow I_3(\Sigma^-)= -1 \end{array}\right\rangle \Rightarrow I=1$$

$$\left.\begin{array}{ll} Q(\Xi^0)= 0 , B(\Xi^0)=1 , S(\Xi^0)=-2 & \Rightarrow I_3(\Xi^0)= \frac{1}{2} \\ Q(\Xi^{-1})= -1 , B(\Xi^{-1})=1 , S(\Xi^{-1})=-2 & \Rightarrow I_3(\Xi^{-1})= -\frac{1}{2} \end{array}\right\rangle \Rightarrow I=\frac{1}{2}$$

"Strange" particle is violated

Charged K were used to produce other strange particles. A K^- which stops in a liquid-H bubble chamber is shown





A) $K^- + p \to \Lambda + \pi^0$

Strong int.:
strangness is conserved.

B) $\Lambda \to p + \pi^-$

Weak int.:
strangeness is violated

K meson interactions

We start from a strangeness state ±1

$S=1$, $B=1$	$K^+p \rightarrow$	K^+p					
	$K^+n \rightarrow$	K^+n	K^0p				
$S=-1$, $B=1$	$K^-p \rightarrow$	K^-p	K^0n	$\pi^0\Lambda^0$	$\pi^+\Sigma^-$	$\pi^0\Sigma^0$	$\pi^-\Sigma^+$
	$K^-p \rightarrow$	$K^0\Xi^0$	$K^+\Xi^-$				
	$K^-n \rightarrow$	K^-n	$\pi^-\Lambda^0$	$\pi^0\Sigma^-$			
	$K^-n \rightarrow$	$K^0\Xi^-$					

For the same energy, K $^-$ produce more particles then K$^+$ since hyperons (B=1) have S=-1

For example: $K^+ + n \rightarrow \bar{\Lambda} + p + n$ $\quad$ [S=1, B=1 $\rightarrow$ S=1, B=1]

(threshold energy of the reaction increases)

Meta-Stable strange hyperons

In cosmic rays and at accelerator 6 metastable hyperons were discovered

	Q	S	m (MeV)	τ (ps)	$c\tau$ (mm)	Principal decays (BR in %)
Λ	0	−1	1116	263	79	$p\pi^-(64)$, $n\pi^0(36)$
Σ^+	+1	−1	1189	80	24	$p\pi^0(51.6)$, $n\pi^+(48.3)$
Σ^0	0	−1	1193	7.4×10^{-8}	2.2×10^{-8}	$\Lambda\gamma(100)$
Σ^-	−1	−1	1197	148	44.4	$n\pi^-(99.8)$
Ξ^0	0	−2	1315	290	87	$\Lambda\pi^0(99.5)$
Ξ^-	−1	−2	1321	164	49	$\Lambda\pi^-(99.9)$

Σo has a lifetime typical of e.m. interactions. Why is the only one which not decay weakly?

Explain the Λ B.R.

The baryons (½)± ad mesons 0-

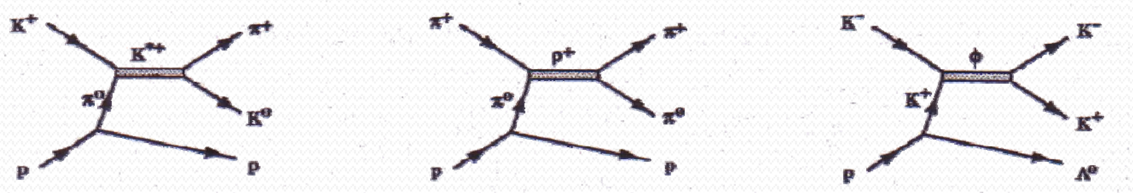
Particle classification based on spin and parity

barioni $\frac{1}{2}^+$	$\boxed{B}$	S	Y	I_3	Q	*mesoni* 0^-	$\boxed{B}$	S	Y	I_3	Q
p	+1	0	+1	+1/2	+1	K^+	0	+1	+1	+1/2	+1
n	+1	0	+1	−1/2	0	K^0	0	+1	+1	−1/2	0
Λ^0	+1	−1	0	0	0	η^0	0	0	0	0	0
Σ^+	+1	−1	0	+1	+1	π^+	0	0	0	+1	+1
Σ^0	+1	−1	0	0	0	π^0	0	0	0	0	0
Σ^-	+1	−1	0	−1	−1	π^-	0	0	0	−1	−1
Ξ^0	+1	−2	−1	+1/2	0	$\bar{K}^0$	0	−1	−1	+1/2	0
Ξ^-	+1	−2	−1	−1/2	−1	K^-	0	−1	−1	−1/2	−1

Mesonic resonances

Vector mesons which decay into pseudoscalar mesons

$J^P = 1^-$ $J^P = 0^-$



K*RESONANCE (K^{*+}; K^{*0}) → M= 894 MeV/c^2; Γ= 51 MeV; I=1/2; S=+1

RISONANZA ρ (ρ^+; ρ^0; ρ^-) → M= 770 MeV/c^2; Γ= 150 MeV; I=1; S=0

ω RESONANCE → M= 783 MeV/c^2; Γ= 8.4 MeV; I=0; S=0

φ RESONANCE → M= 1019 MeV/c^2; Γ= 4.4 MeV; I=0; S=0

Mesonic Resonances 1^-

	$m\ (MeV/c^2)$	$\Gamma\ (MeV)$	*decadimento*
K^*	894	51	$K\pi$
ρ	770	150	$\pi\pi$
ω	783	8.4	$\pi^+\pi^0\pi^-$
ϕ	1019	4.4	K^+K^- $K^0\bar{K}^0$ $\pi^+\pi^0\pi^-$

mesoni 1^-	S	Y	I_3	Q
K^{*+}	$+1$	$+1$	$+1/2$	$+1$
K^{*o}	$+1$	$+1$	$-1/2$	0
ρ^+	0	0	$+1$	$+1$
ρ^0	0	0	0	0
ρ^-	0	0	-1	-1
ω	0	0	0	0
$\bar{K}^{*o}$	-1	-1	$+1/2$	0
K^{*-}	-1	-1	$-1/2$	-1
ϕ	0	0	0	0

Baryonic Resonances: Σ^* e Ξ^*

Resonances with strangeness were also found

RESONANCE Σ^*

Larghezza Γ= 37 MeV; $J^P=3/2^+$; I=1; S=-1

$k^- p \rightarrow \pi^- \Sigma^{*+} \rightarrow \pi^- \Lambda^o \pi^+$ — 1382.8 MeV/c²

$k^- p \rightarrow \pi^o \Sigma^{*o} \rightarrow \pi^o \Lambda^o \pi^o$ — 1383.7 MeV/c²

$k^- p \rightarrow \pi^+ \Sigma^{*-} \rightarrow \pi^+ \Lambda^o \pi^-$ — 1387.2 MeV/c²

RESONANCE Ξ^{**}

Larghezza Γ= 9 MeV; $J^P=3/2^+$; I=1/2; S=-2

$k^- p \rightarrow k^o \Xi^{*o}$ — 1531.8 MeV/c²

$k^- p \rightarrow k^+ \Xi^{*-}$ — 1531.8 MeV/c²

$\Xi^{*o} \rightarrow \Xi^- \pi^+$ o $\Xi^o \pi^o$

$\Xi^{*-} \rightarrow \Xi^- \pi^o$ o $\Xi^o \pi^-$

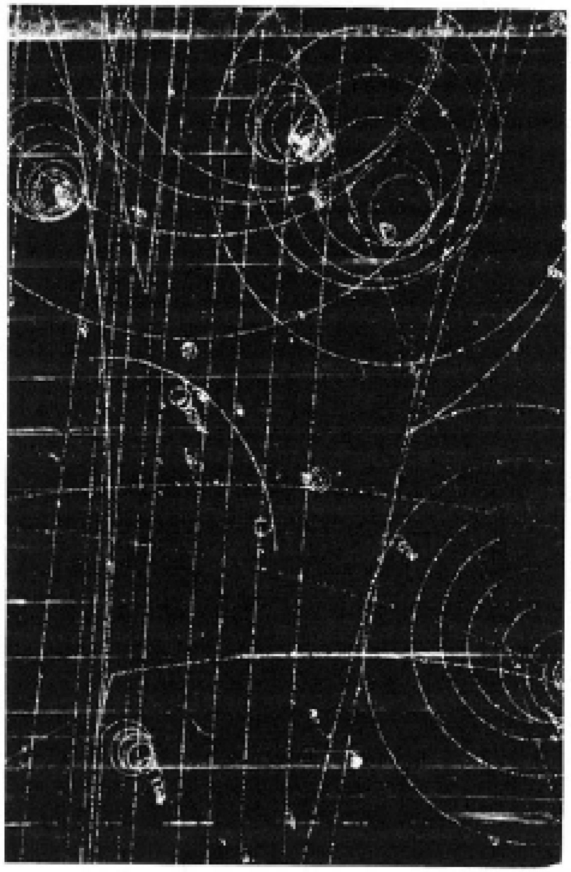
Ξ^- e Ξ^o are baryons with $J^P=1/2^+$; S=-2; I=1/2

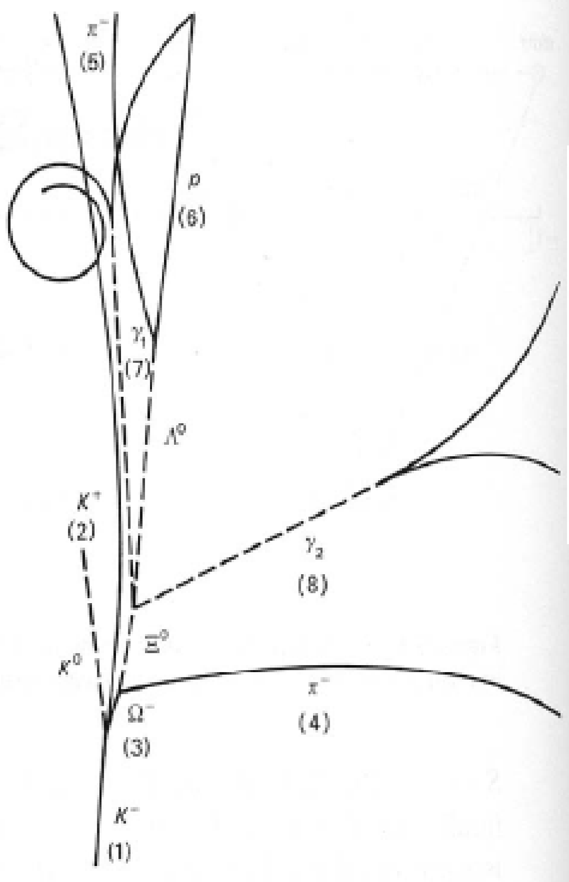
Baryonic resonances $(3/2)^{\pm}$

$barioni\ \frac{3}{2}^+$	S	Y	I_3	Q
Δ^{++}	0	$+1$	$+3/2$	$+2$
Δ^{+}	0	$+1$	$+1/2$	$+1$
Δ^{0}	0	$+1$	$-1/2$	0
Δ^{-}	0	$+1$	$-3/2$	-1
Σ^{*+}	-1	0	$+1$	$+1$
Σ^{*o}	-1	0	0	0
Σ^{*-}	-1	0	-1	-1
Ξ^{*o}	-2	-1	$+1/2$	0
Ξ^{*-}	-2	-1	$-1/2$	-1
Ω^{-}	-3	-2	0	-1

The discovery of the Ω^-

The Ω^- was foreseen by Gell-Mann on the basis of his particle classification(eightfoldeightfold way)





$K^- + p \to \Omega^- + K^+ + K^0$

$\hookrightarrow \Xi^0 + \pi^-$ ($\Delta S = 1$ weak decay)

$\hookrightarrow \pi^0 + \Lambda$ ($\Delta S = 1$ weak decay)

$\hookrightarrow \pi^- + p$ ($\Delta S = 1$ weak decay)

$\hookrightarrow \gamma + \gamma$ (e.m. decay)

$\downarrow \quad \downarrow$

$e^+e^- \quad e^+e^-$.