Strangeness

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Detection of particles in the 40/50's

- Cloud chamber (or Wilson chamber, 1912)
  - Sealed chamber with super-saturated vapor (water)
  - Ionizing radiation creates electric charges
  - Adiabatic expansion through a membrane to condensate drops
  - Illumination of drops and collection of pictures
  - Magnetic field for momentum measurement
  - Electric field to clean up residual free electric charge
- Bubble chamber (Glaser, 1952)
  - Sealed chamber with super-heated liquid
  - Ionizing radiation creates electric charges
  - Bubbles form around electric ions
  - Conceptually similar to cloud chamber but better because of:
    - higher density: larger ionization, better track definition and spatial resolution
    - higher stopping power
- Photographic emulsions (~1947)
  - Extremely good spatial resolution (μm vs mm of cloud/bubble chambers)
  - Still used in some modern experiments

Cloud chamber

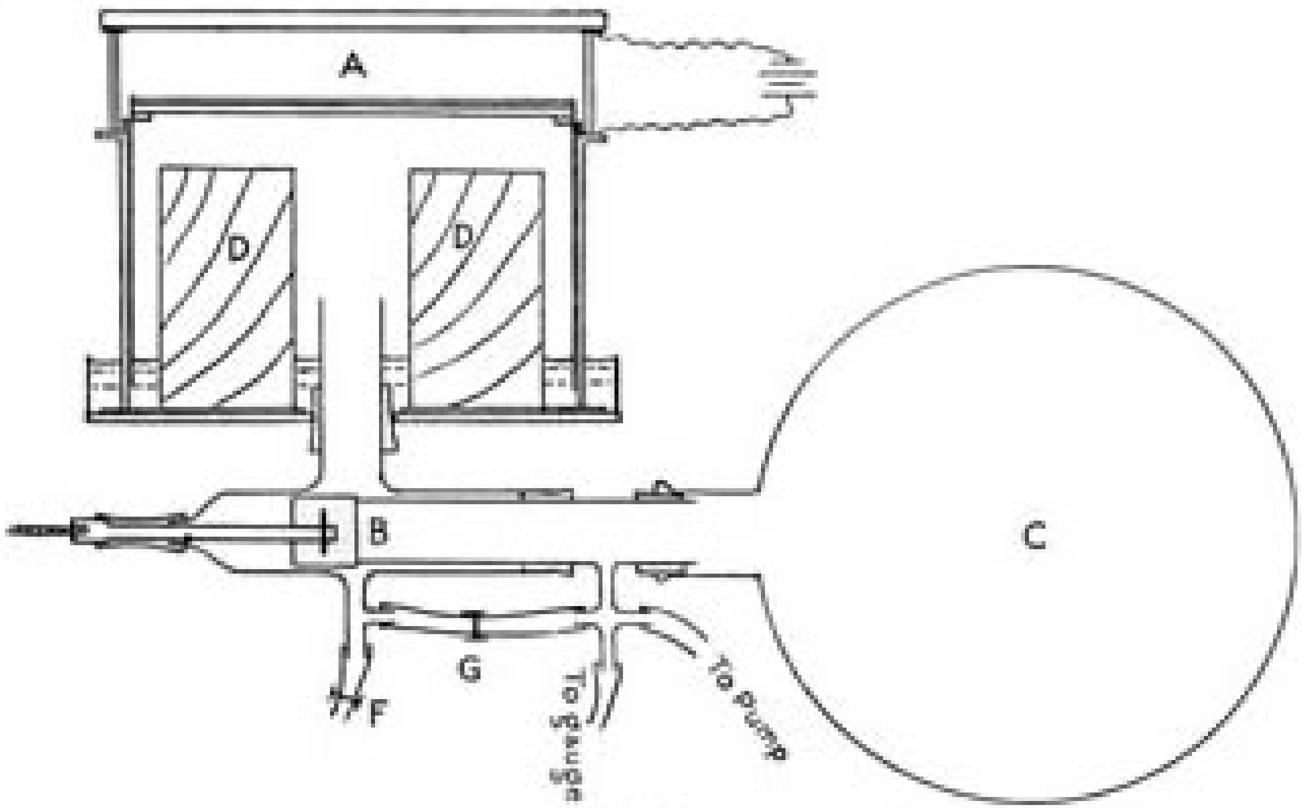
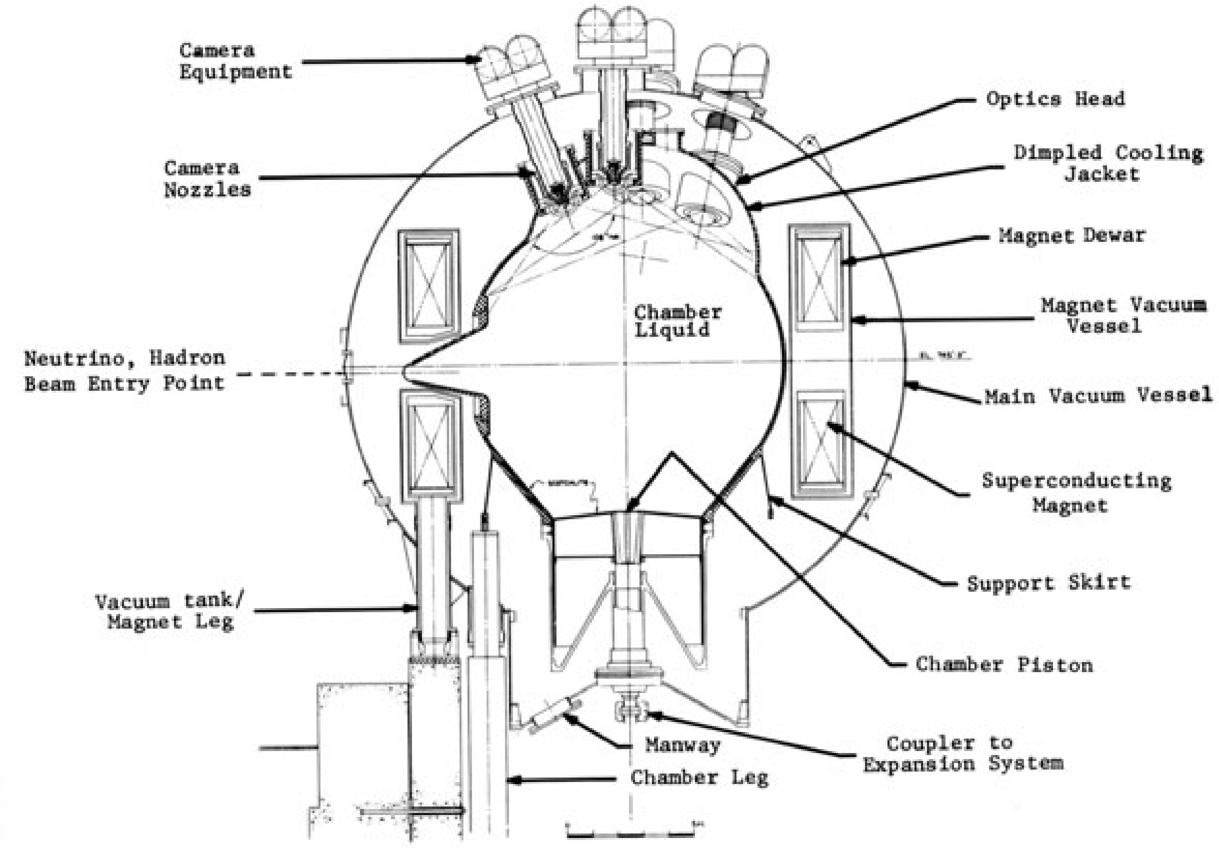


Fig. 1.

A diagram of Wilson's apparatus. The cylindrical cloud chamber ('A') is 16.5cm across by 3.4cm deep.

Bubble chamber

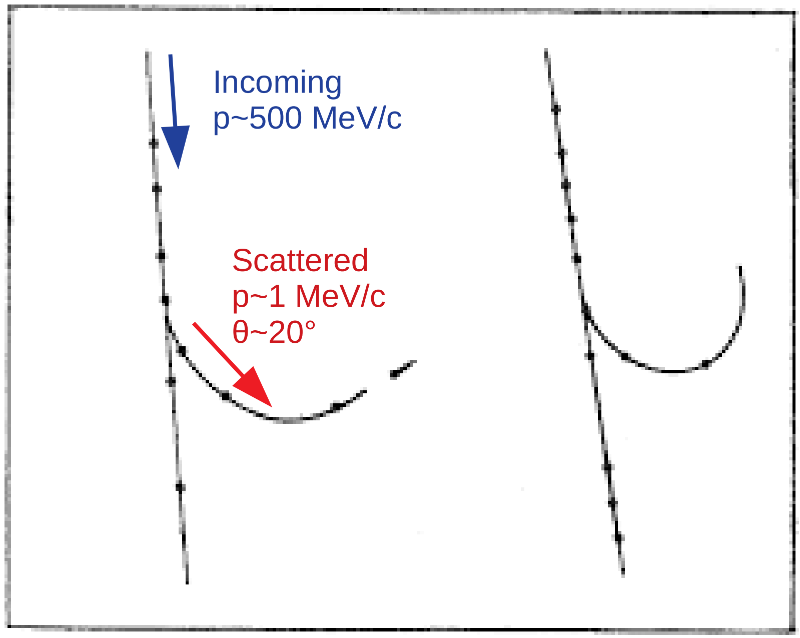


Picture of 15 ft bubble chamber at Fermilab (Oct 1971)

Observations of strange mesons

First observations of strange particles in cosmic rays.

Leprince-Ringuet and Lhéritier (1943)
Analysis of 10000 triggered pictures in a 75x15x10 cm^3 cloud chamber with B=0.25 T magnetic field.
One picture showed an incident particle with momentum ~500 MeV/c producing a secondary particle of ~1 MeV/c.



Dessin stéréoscopique de la collision.

Assuming elastic scattering on electron it was derived for the mass of the incoming particle X: M_X=506 MeV ± 12%
Incompatible with a pion

$$M_X = P_X \sqrt{\frac{E_e + m_e}{E_e - m_e} \cos^2 \theta_e - 1}$$

Observations of strange mesons

Rochester and Butler (1947)
Observation of forked tracks in cloud chamber pictures:

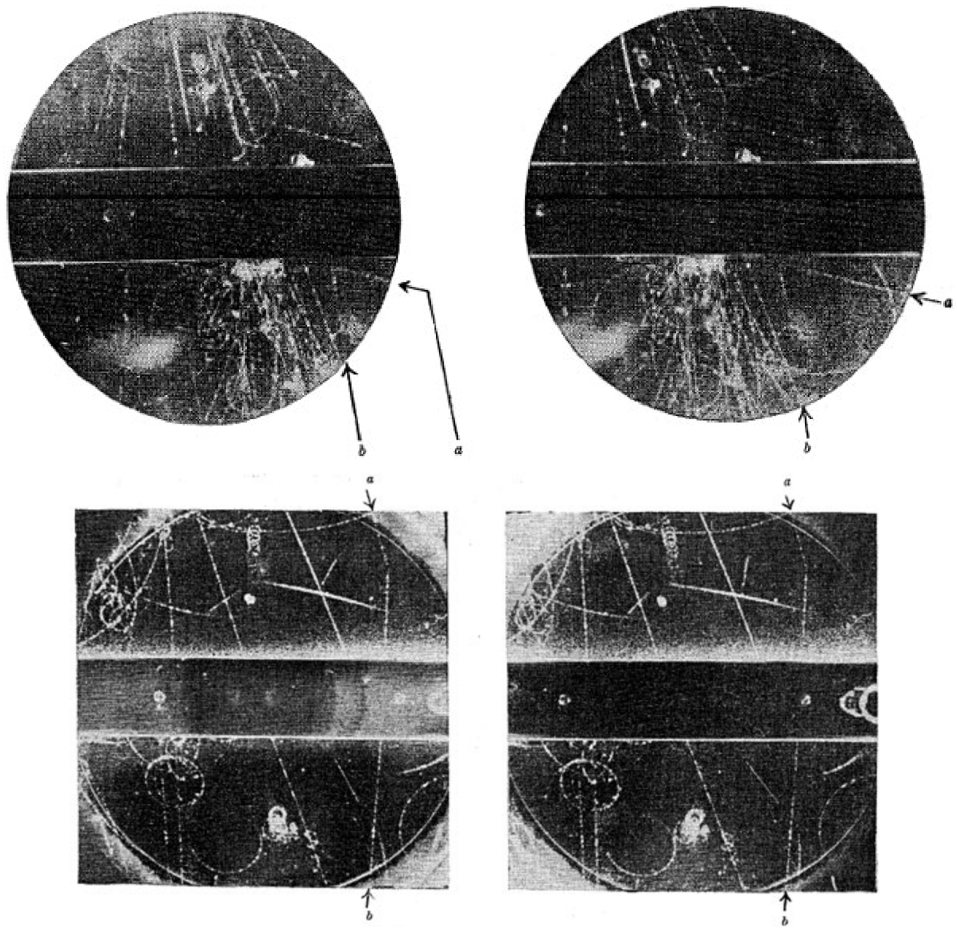
- 2 prongs with no additional charged track
- Apex in the gas (just in a few cases in a 3 cm lead plate)

therefore collision processes excluded

First event:
interpreted as decay of neutral particle in 2 charged particles

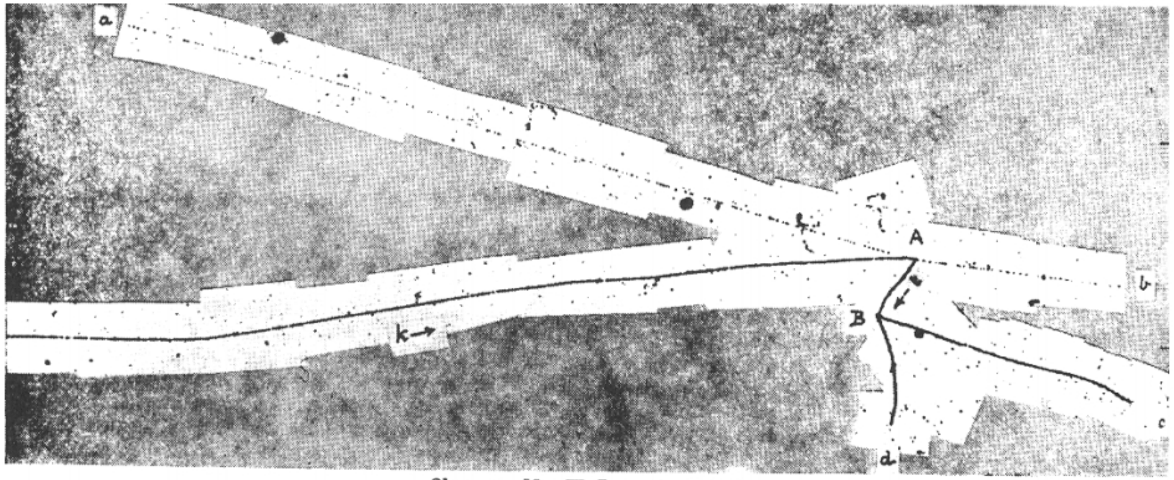
Second event:
interpreted as decay of charged particle in 1 charged + neutral

Extracted masses compatible with ~500 MeV



Observations of strange mesons

Bristol group (Powell et al., 1949)
Decay of a charged particle from cosmic rays in 3 charged particles observed in emulsions



Observer: Mrs. W. J. van der Merwe

Mass determination in emulsions combining 2 information:

- grain density ~$1/v^2$ for non-relativistic particles (slow-down of incoming particle towards point of decay A)
- deflections by multiple scattering ~$1/p$

Also in this case extracted mass ~500 MeV

Observations of strange mesons

Bristol group (O'Cellaigh et al., 1951)

With emulsions, evidence of the decay:
$K^{\pm} \rightarrow \mu^{\pm} + ?$

Mass of the incoming particle measured from grain density and multiple scattering
M=526±70 MeV

Figure 3.1: A κ (K) meson stops at P, decaying into a muon and neutrals. The muon decays at Q to an electron and neutrals. The muon track is shown in two long sections. Note the lighter ionization produced by the electron, contrasted with the heavy ionization produced by the muon near the end of its range. The mass of the κ was measured by scattering and grain density to be 562 ± 70 MeV (Ref. 3.4).

Dalitz analysis

Determine J^P of the $K^+ \rightarrow \pi^+ \pi^+ \pi^-$
Because of kinematic constraints the decay can be represented by 2 independent quantities (pion energies).

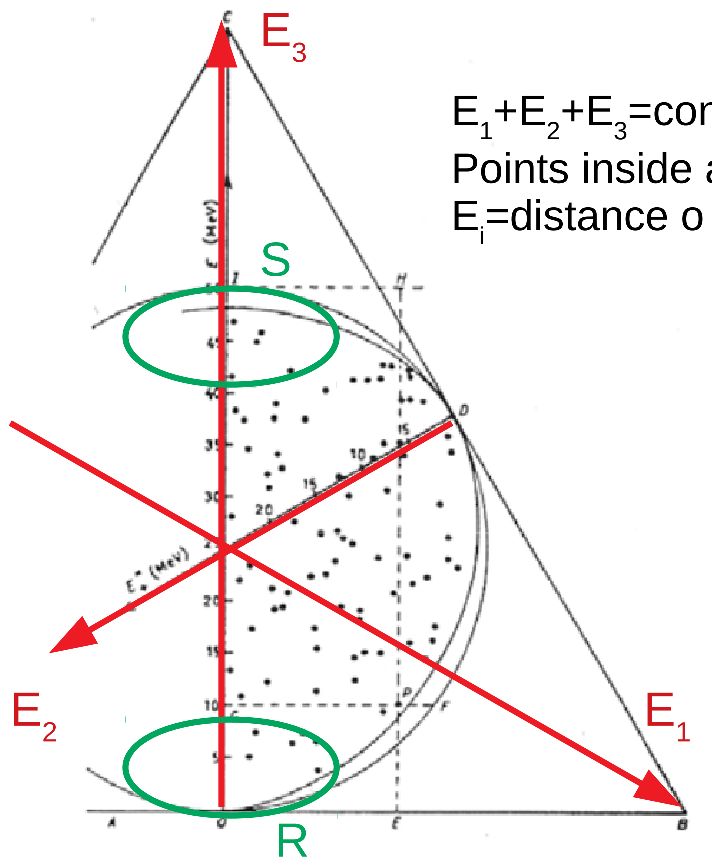
- Let L_1 be the angular momentum of the 2 like pions in the system, which should be even by Bose symmetry
- Let L_2 be the angular momentum of the opposite sign pion with respect to the system of the other 2

Dalitz worldwide compilation of $K \rightarrow 3\pi$ events.

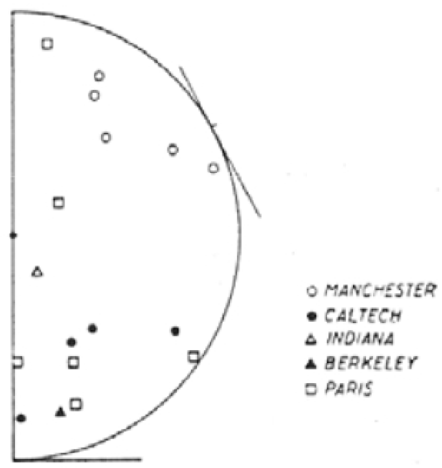
- If $L_1 = L_2 = 0$ plot uniformly filled
- If $L_1 > 0$ plot depleted in region S (two like pions at “rest”)
- If $L_2 > 0$ plot depleted in region R (opposite sign pion with low energy)
- Intrinsic parity of the π is -1

No depletion observed: suggests $J^P = 0^-$ (if parity conserved in decay)

“τ-θ puzzle”: $K^+ \rightarrow \pi^+ \pi^0$ with the same mass, is it the same particle?
(Now we know the answer: yes, parity not conserved in decay)



$E_1+E_2+E_3=\text{const}$
Points inside a circle, in a triangle
E_i=distance o the point from side i



Observations of strange hadrons (hyperons)

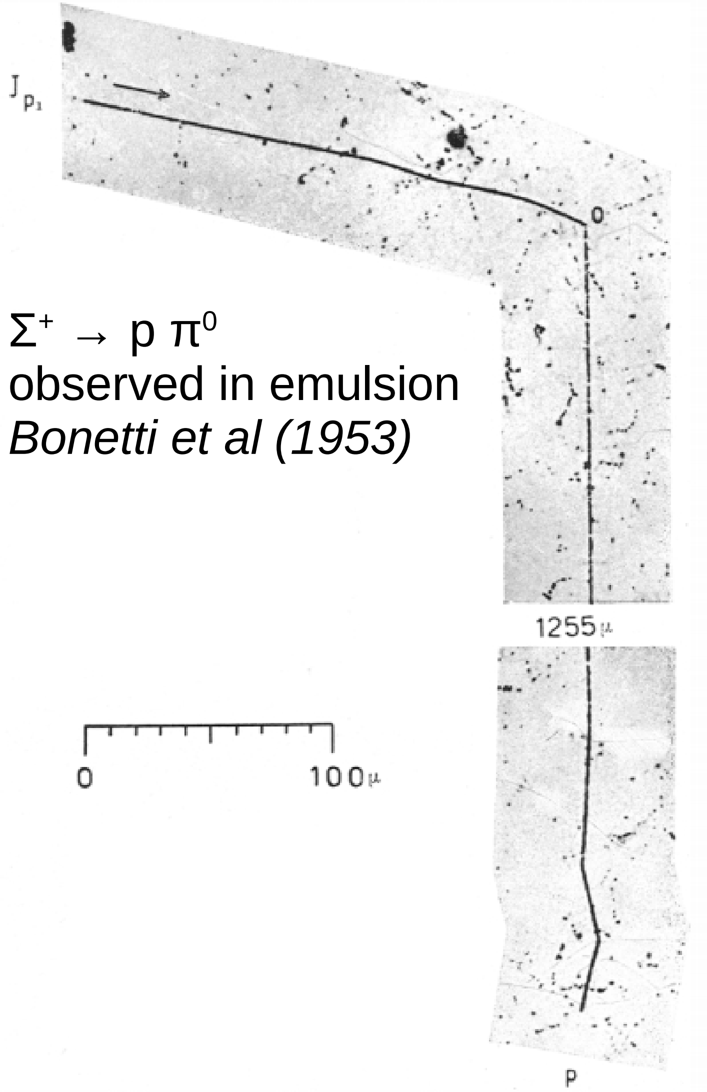
First evidence of strange baryons Λ and $\Sigma^{\pm}$ in cosmic rays
Presence of protons in the decay products

$\Lambda \rightarrow p\,\pi^-$
observed in a bubble chamber
Anderson et al (1953)

Figure:
Liquid hydrogen bubble chamber at BNL

High energy proton incoming (below) producing several charged particles and a Λ that decays to $p\,\pi^-$

$\Sigma^+ \rightarrow p\,\pi^0$
observed in emulsion
Bonetti et al (1953)

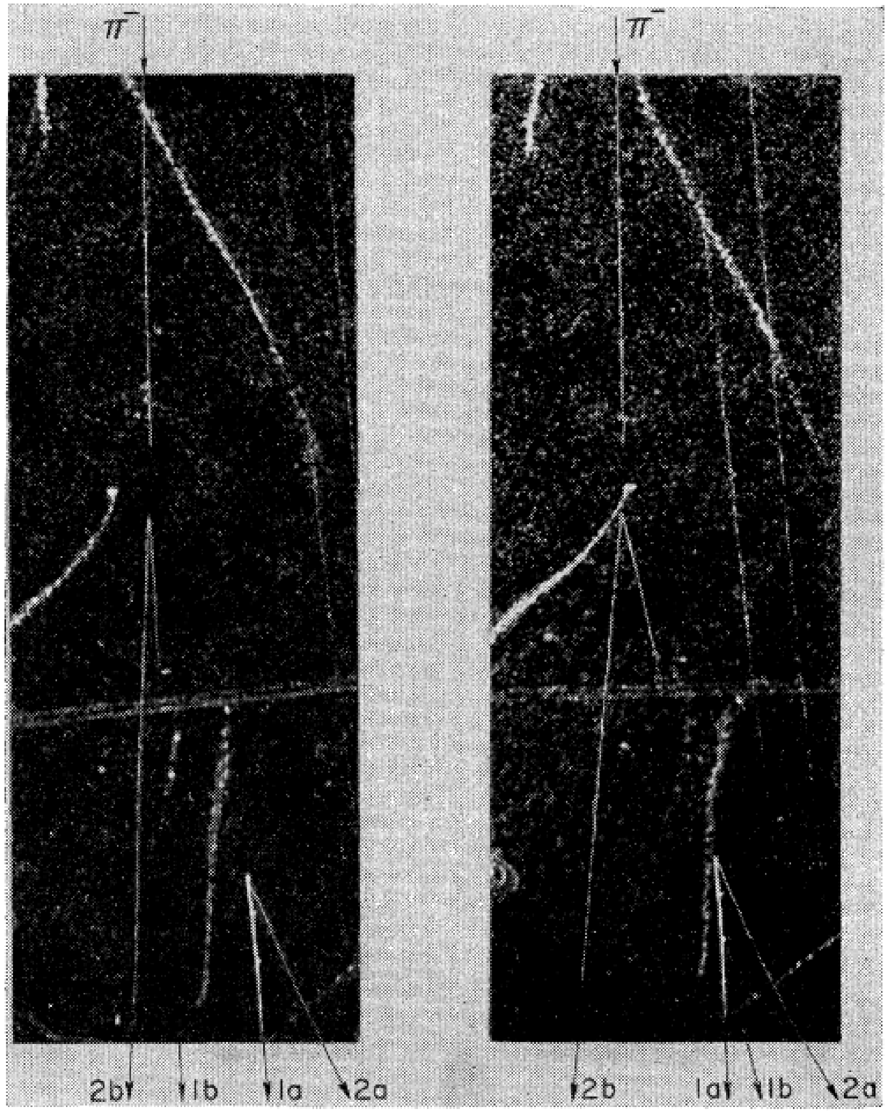


Observations with proton beams

Cosmotron (1.3 GeV p accelerator in Brookhaven, 1952)
Bevatron (6.2 GeV p accelerator in Berkeley, 1954)

Observation of Λ and K frequently produced together

Fowler et al. (BNL 1954)



The strangeness at the end of the 40s

- Particles produced in abundance → Strong interaction
- Decay into hadrons → Strongly interacting
- Too long lifetime 10^{-10} s → Consistent with weak interaction (strong decay processes have typical lifetimes of the order $\sim 10^{-23}$ s)

Solution from ideas of Pais and Gell-Mann: a new additive quantum number (*S, strangeness*) is introduced. This number is conserved in the strong interactions but not in the weak. For “old” particles S=0.

It follows that:

- strange particles produced in pairs
- $\pi^- p \rightarrow K^0 \Lambda$ allowed, $\pi^- p \rightarrow K^0 n$ forbidden
- $K^0 \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow \pi^- p$ allowed but weak interactions

Gell-Mann Nishijima formula links the strangeness to the electric charge (Q), the baryon number (B) and the isospin (I_z): $Q=I_z+(B+S)/2$

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Strangeness assignment

- Mesons:
  - π^+, π^0, π^- (isospin triplet) → S=0
  - K^0, K^+ (isospin doublet) → S=+1
  - K^-, $\bar{K}^0$ (isospin doublet) → S=-1 (opposite strangeness for antiparticles)
- Baryons:
  - p, n (isospin doublet) → S=0
  - Λ (isospin singlet) → S=-1
  - Σ^-, Σ^0, Σ^+ (isospin triplet) → S=-1
  - Ξ^-, Ξ^0 (isospin doublet) → S=-2
  - Ω^- (isospin singlet) → S=-3

Production and decay

Strange particle production: strong interaction → S is conserved
Decay of strange particles: weak interactions → $|\Delta S|=1$

Production	Allowed	Forbidden
$\pi^- p \rightarrow$	$K^0 \Lambda$ $K^+ \Sigma^-$ $\Xi^0 K^0 K^0$ $\Xi^- K^+ K^0$	$\pi^0 \Lambda$ $K^- p$ $\Xi^0 K^0 \pi^0$ $\Xi^+ K^- K^0$

Decay	Allowed
$\Lambda \rightarrow$	$\pi^- p$
$K^+ \rightarrow$	$\pi^+ \pi^0$
$\Sigma^+ \rightarrow$	$\pi^0 p$, $\pi^0 n$
$\Sigma^0 \rightarrow$	$\Lambda \gamma$ (E.M. $\tau \sim 10^{-20}$ s)
$\Xi^0 \rightarrow$	$\Lambda \pi^0$

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