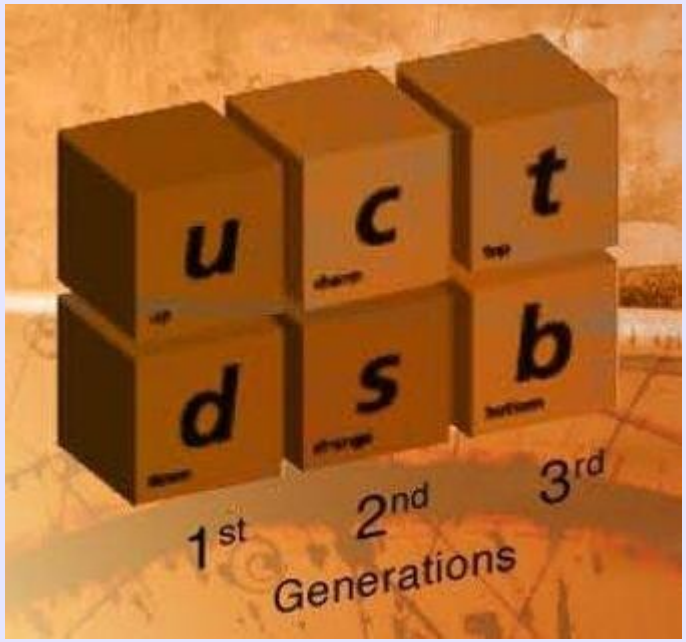
THE BIRTH OF THE QUARK MODEL

Lina Galtieri (LBNL)

Luie created an incredible environment that lead to important discoveries.
He had a dedicated staff of physicists, exceptional graduate students, an army of very talented engineers and programmers, a greater army of scanners working 24-7.

The commander in chief encouraged everyone to try new ideas and go beyond what they thought to be their limitations.

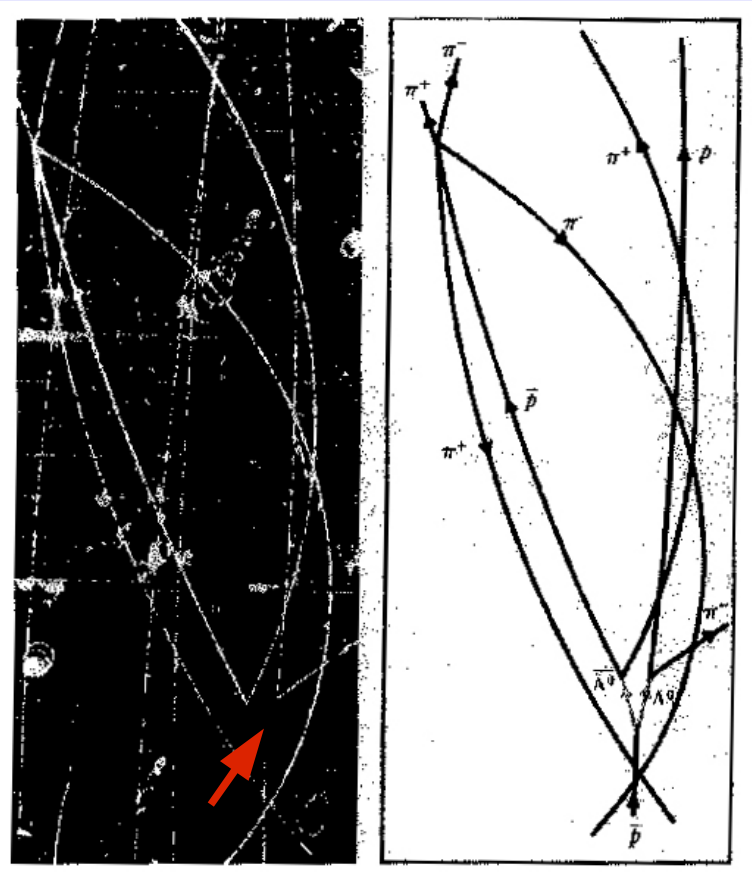
It worked!



The building blocks of matter today.

u, d, s are the ones LWA contributed to.

Event Reconstruction



Antiproton beam in the 72” Bubble Chamber

The whole event is reconstructed by combining the vectors that represent each particle.

This event is

$$p\,\bar{p} \rightarrow \Lambda\,\bar{\Lambda}$$

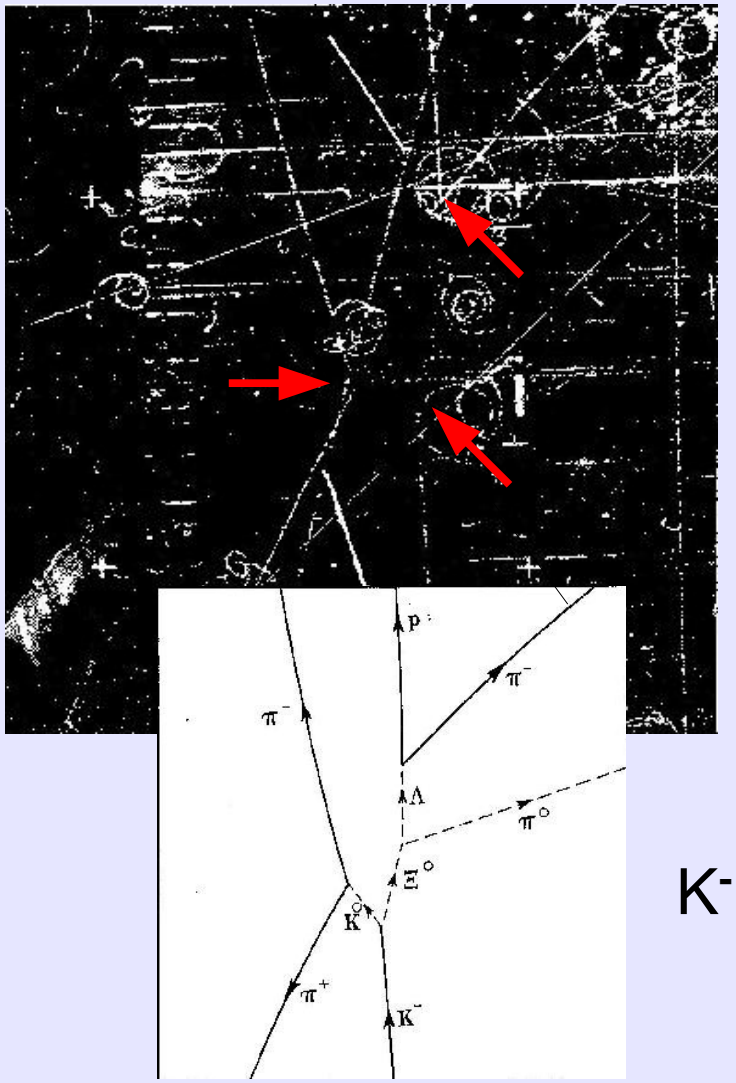
particles are found this way.

Both the Λ and $\bar{\Lambda}$ were already known

Greek letters were used for many of the new particles

Ξ^0 DISCOVERY

March 1959 15” Bubble Chamber



Nishijima and Gell Mann had predicted the Ξ^0 existence

$K^- p \rightarrow K^0 \quad \Xi^0$

6 Scientists 'Trap' New Particle Of Atom After 70,000 Photos

By ROBERT K. PLUMB

American scientists have reached a major landmark in the exploration of inner space.

A team of six at the University of California, after working a year and a half with the nation's most powerful scientific instrument, the Bevatron, has obtained a ghostly picture of the atomic particle called the Xi zero.

The Xi particle has zero electrical charge. So it left no tracks to be photographed in experiments in which known atomic particles were traced as they plunged through a tank of liquid hydrogen.

But the presence of one Xi zero particle has been deduced from ghostly effects in a photograph that shows the motions of known particles to be peculiarly skewed by "something." The something in the photograph is the Xi zero particle.

An Xi zero, according to the new evidence, weighs abou 2,570 times as much as an electron, and it has a lifetime o about one ten-billionth of a second.

Seventy thousand photograph were taken to catch one Xi zero in motion. A photograph take just before Christmas has been identified after rigorous analysis as a genuine Xi zero ghost track. The finding will be published in Physical Review Letters, a publication of the American Physical Society.

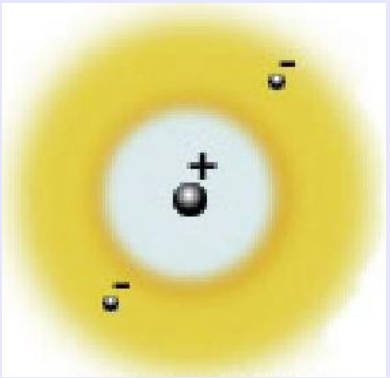
Mathematical calculations two years ago by Dr. K. Nishijima a Japanese physicist, and Dr Murray Gell-Mann of the California Institute of Technology predicted that the Xi zero should exist. The new photograph proves it, the University of California team reported.

An Xi zero is one of thirt

Continued on Page 28, Column 3

The New York Times
Published: March 5, 1959

KNOWN PARTICLES BEFORE THE HBC



Which particles were known in 1957?
Protons, neutrons, electrons that made the atoms

Leptons (light particles): electrons, muons, neutrino

Mesons (mid-weight): Pions, kaons
kaons were considered strange because they were produced in cosmic rays and accelerator experiments, but decayed slowly

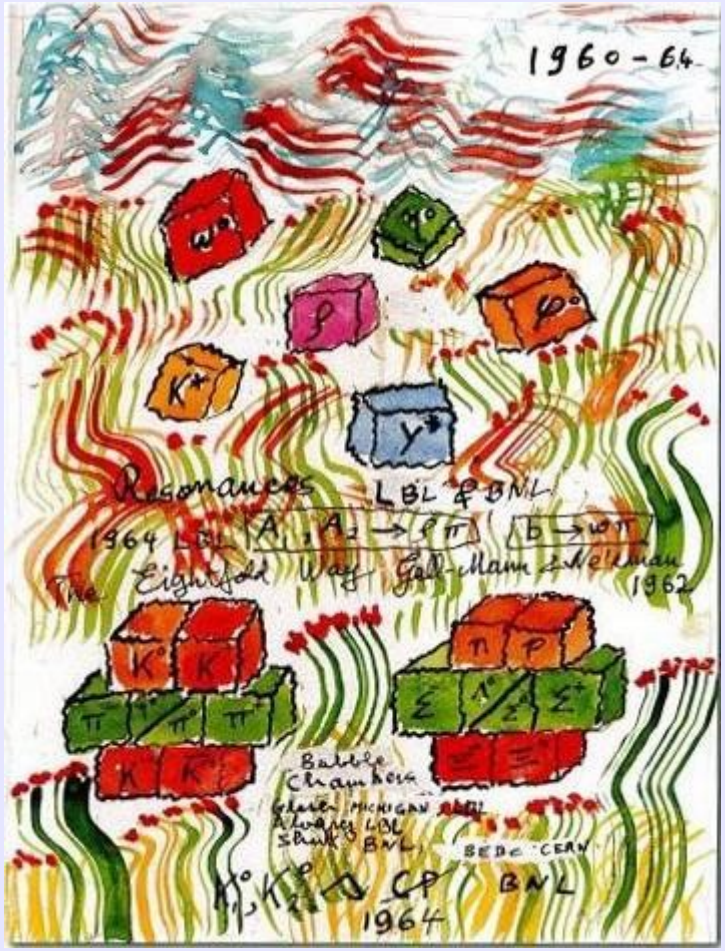
Baryons (heavy particles): proton, lambdas, sigmas, and xis
All of them, except the proton, strange

Strangeness was a property of many particles, but in production it had to be conserved

	π^-	p	->	K^+	Σ^-	associate production
S	0	0	->	+1	-1	strangeness of final particles =0

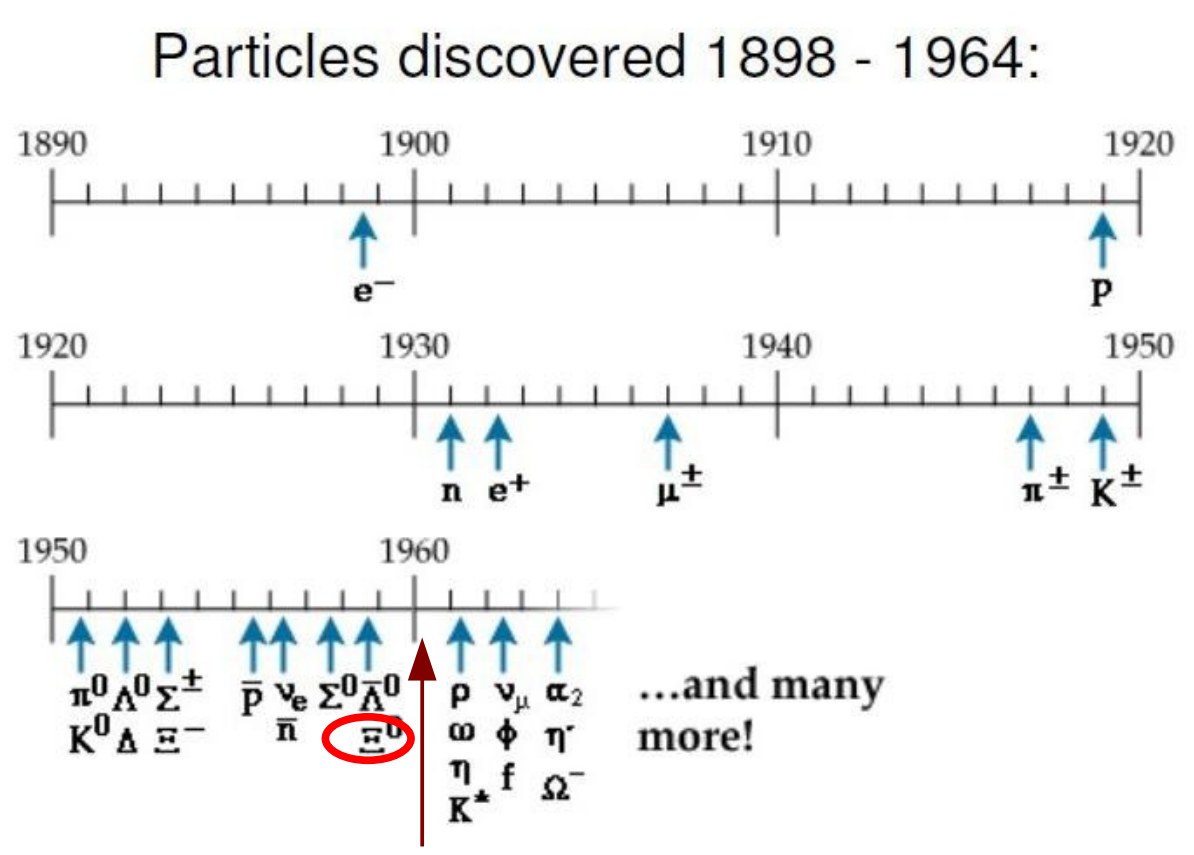
Particles discoveries (1955-1964)

Artist's view: “A brief history of particle physics in brush strokes” by Gerson Goldhaber



THE PARTICLE EXPLOSION

Before 1960 most particles were discovered with cloud chambers or nuclear emulsions



After the Ξ^0 18 more particles were discovered or co-discovered in Luie's hydrogen bubble chambers

The Ξ^0 is a "stable" (lifetime ~10^{-10}sec) particle, while the other 18 are resonances

Enrico Fermi once said to his student (and future Nobel Laureate) Leon Lederman,

"Young man, if I could remember the names of these particles, I would have been a botanist!"

RESONANCES

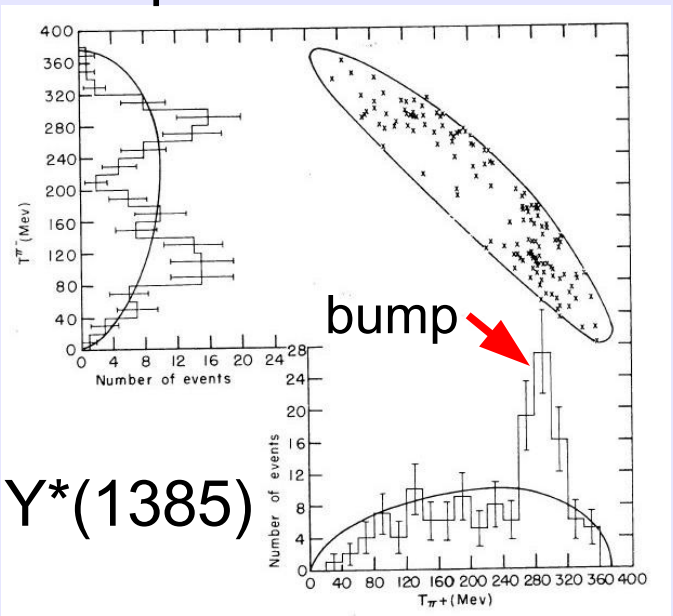
The Λ and the Ξ^0 seen earlier have a lifetime of ~10^{-10} sec. they decay into other particles, and we can see a gap in the film.

A new class of particles, the resonances, decay in a very short time (10^{-23} seconds): no gap in the film is seen.
The resonances are found by a peak in the kinetic energy (T) of a particle in the event. Only one resonance, Δ++, was known before the HBC's were constructed.

Here is the first resonance seen in HBC by "Bump Hunting" (looking for peaks). Luie credits Bill Graziano and Stan Wojcicki for having invented the technique.

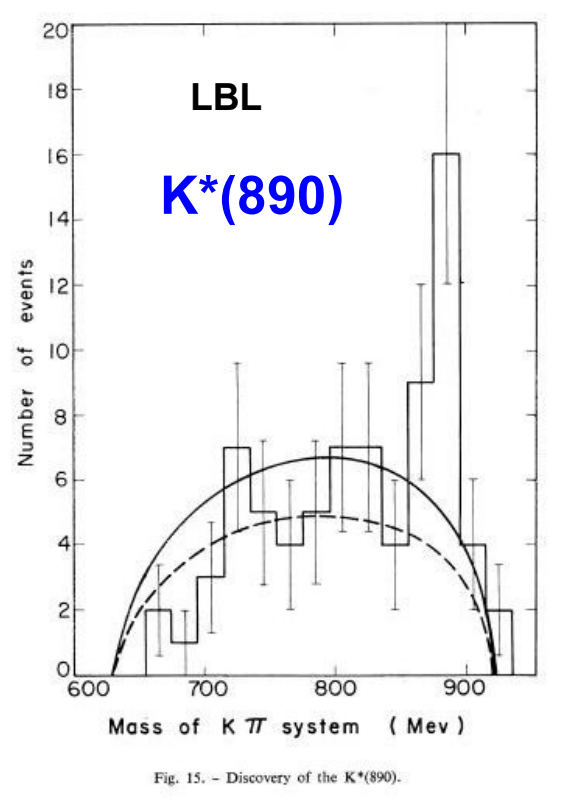
Discovery by:
Alston, Alvarez, Eberhard, Good, Graziano, Ticho,Wojcicki

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

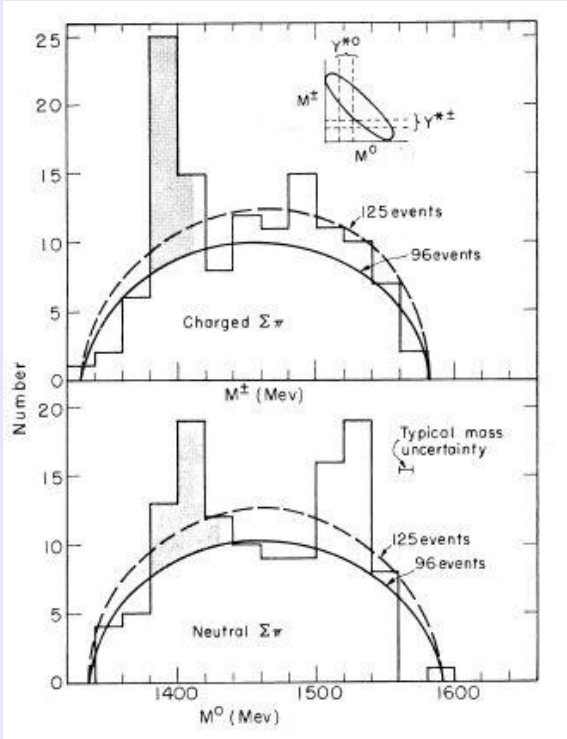


Hydrogen Bubble Chamber Discoveries

Resonances: 8 by the LRL group, 10 co-discovered by LRL or by groups who used the LRL film



Σ(1385) and Y*⁰(1405)



Y*(1385)	baryon	LBL	1960
K*(890)	meson	LBL	1960
Y*(1405)	baryon	LBL	1960
ρ meson	BNL+	LBL	1961
ω meson		LBL	1961
η meson	JH/NW	+LBL	1961
Y*(1520)	baryon	LRL	1962
φ(1019)	meson	BNL/SY/UCLA	
Y*(1660)	baryon	LBL	1962
X*(1530)	baryon	UCLA/BNL/SY	
Y*(1765)	baryon	LBL	1963
A1 meson		GT +LBL	1964
A2 meson		GT +LBL	1964
η' meson		BNL/SY+LBL	1964
D(1285)	meson	LBL	1965
X*(1815)	baryon	EUC+LBL	'65
Y*(2100)	baryon	BNL+LBL	'66
Y*(2030)	baryon	BNL+LBL	'66

Discovered by Alston et al. (LBL)

THE BIRTH OF THE QUARK MODEL

1961: M. Gell-Mann and Y. Ne'eman proposed the Eightfold Way a classification scheme that groups together particles with the same quantum numbers J^{PC} (angular momentum, spatial and charge symmetry).
Other properties are: electric charge (Q), z component of the Isospin (I_3), strangeness (S), mass (m).

The Eightfold Way : Gell-Mann took this title from Buddha's teaching as the appropriate path to Nirvana.

Everything comes from 8's. This can be obtained using SU(3), an abstract group which has as building blocks three quarks. They may or may not be real. They had not been found, but were useful to put some order in the particle Zoo.

Zweig also proposed a scheme by which three “aces” could be used to classify all known particles.

JP=0$^-$ MESON NONET

	u	d	s	
Q	+2/3	-1/3	-1/3	quarks, q
Q	-2/3	+1/3	+1/3	antiquarks, $\bar{q}$

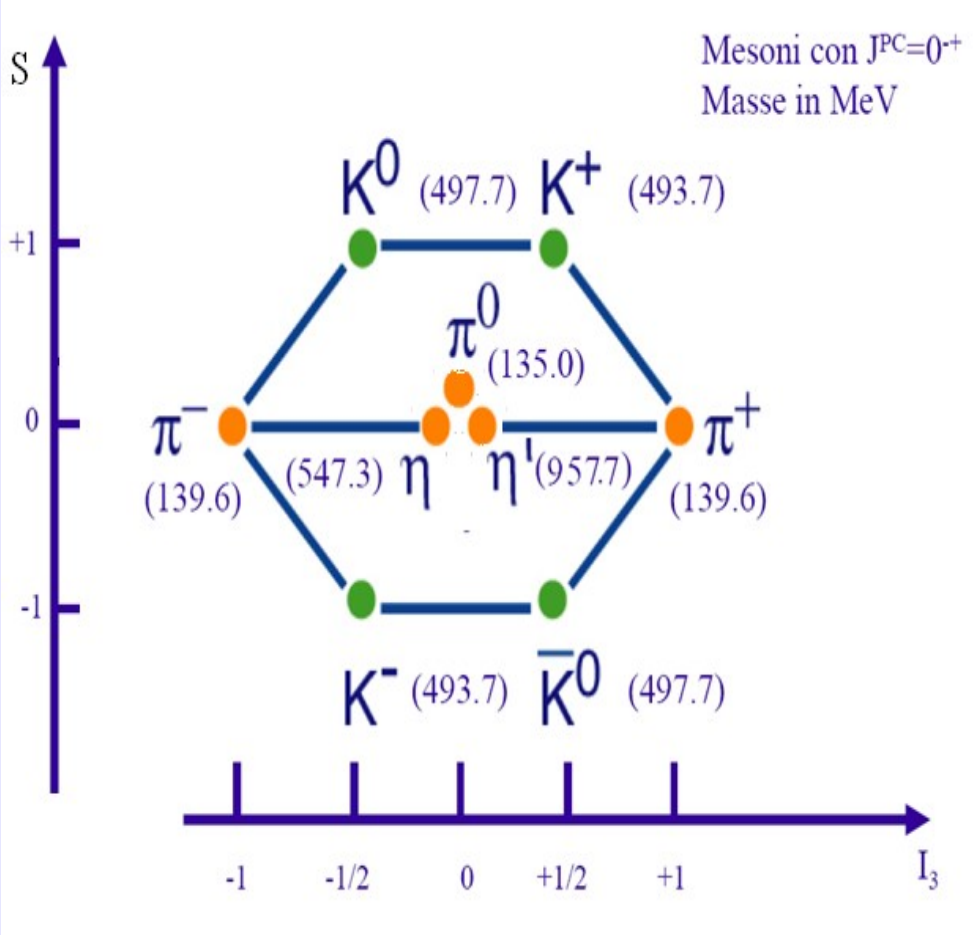
A meson consists of a q and $\bar{q}$
SU(3) algebra expects

$3 \otimes \bar{3} = 8 \oplus 1$ octet + singlet

There were only 7 mesons when this proposal was made. The discovery of the η (1961) was a big success for the model.

The η' was discovered in 1964

octet + singlet



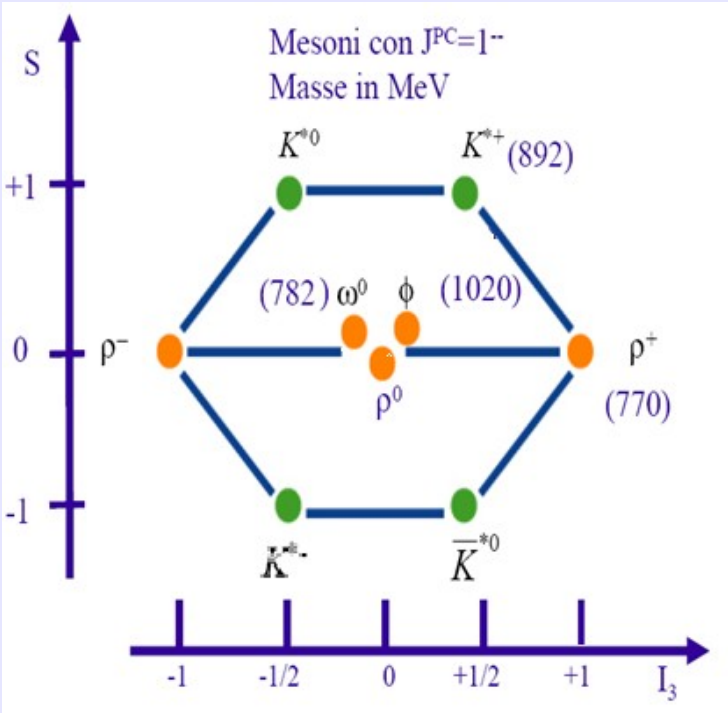
Plot courtesy of Ida Peruzzi, University of Perugia

THE JP=1⁻ MESON NONET

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.776	1

π+ and ρ+ have the same quark content, but different spins

This entire nonet was discovered (K*, ω) or co-discovered (ρ, ϕ) in Luie's bubble chambers.



Plot courtesy of Ida Piccolo, University of Perugia

BARYON MULTIPLETS

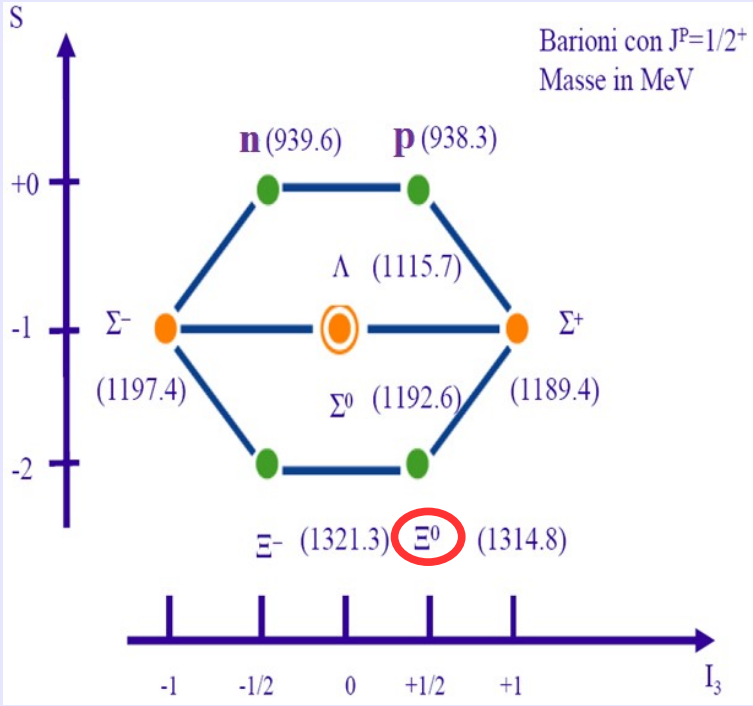
Baryons are made of three quarks.

proton

SU(3) algebra expects:

$3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$

JP=1/2⁺ Baryon nonet

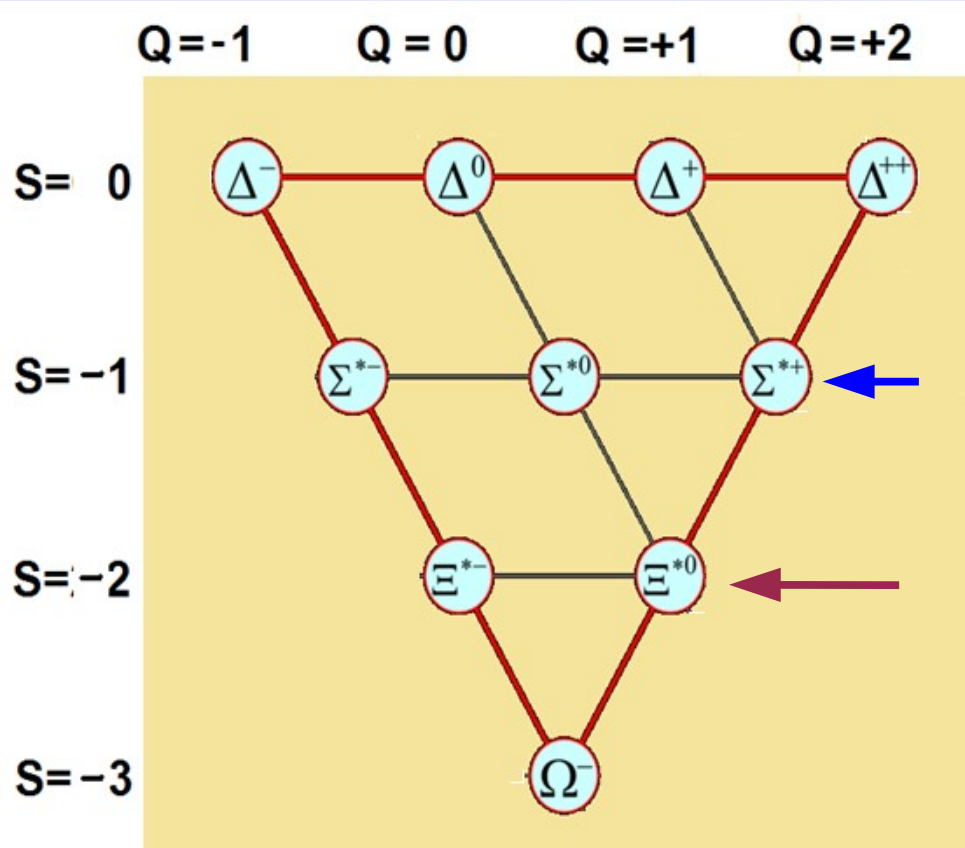


Plot courtesy of Ida Piccolo, University of Perugia

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathbf{p}}$	antiproton	$\bar{\mathbf{u}}\bar{\mathbf{u}}\bar{\mathbf{d}}$	–1	0.938	1/2
n	neutron	**udd**	0	0.940	1/2
Λ	lambda	**uds**	0	1.116	1/2
Ω^-	omega	**sss**	–1	1.672	3/2

BARYON DECUPLET

Baryon Decuplet JP = 3/2+



Plot courtesy of Ida Peruzzi, University of Perugia

The Σ^* is the Y*(1385), the first resonance discovered at LRL

The Ξ^* was co-discovered by a European Coll. and LRL (1965)

The Ω^- mass was expected to be ~1670 MeV, not reachable at the Bevatron. It was discovered at BNL in their 80" HBC in 1964

The Ω^- discovery established the validity of the quark model

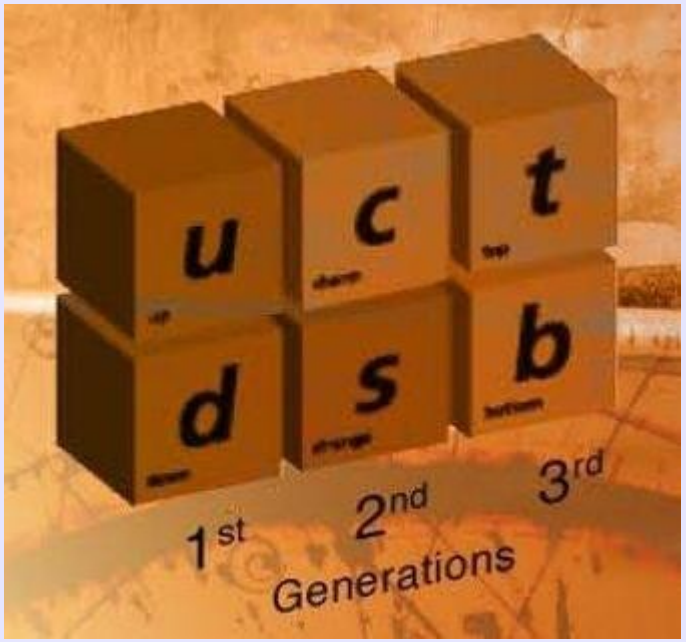
Nobel Prize Motivation

The Nobel Prize in Physics 1968 was awarded to Luis Alvarez

"for his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using hydrogen bubble chamber and data analysis".

Luie took to Stockholm eight of his collaborators and their spouses

NOW THEY ARE SIX BUILDING BLOCKS



Charm : discovered in 1974 at SLAC/BNL
Bottom : discovered in 1979 at BNL
Top : discovered in 1995 at FNAL

More combinations of q $\bar{q}$ can be made

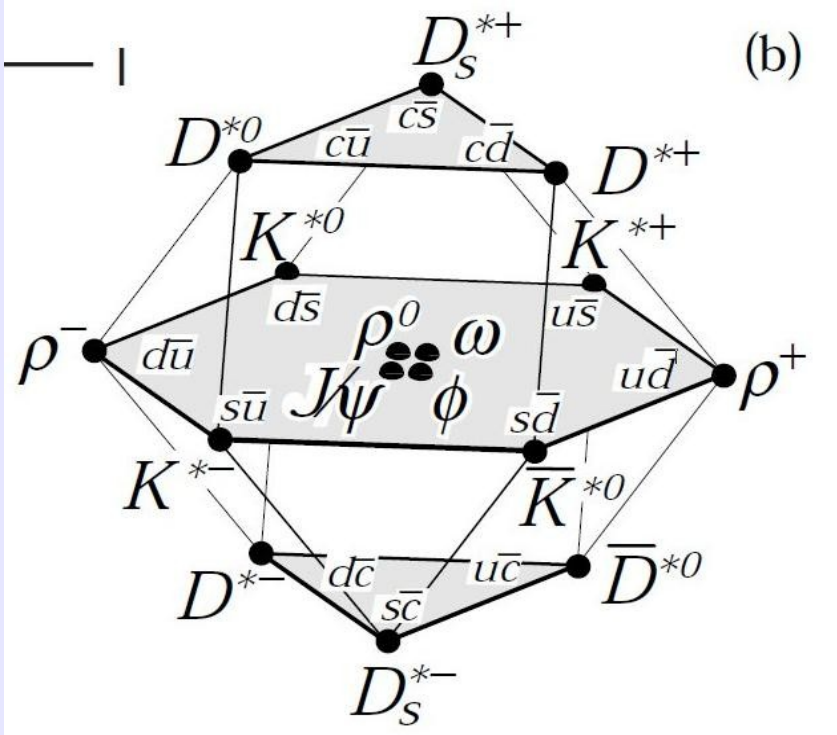
More combinations of q q q can be made

There are 190 mesons and 150 Baryons

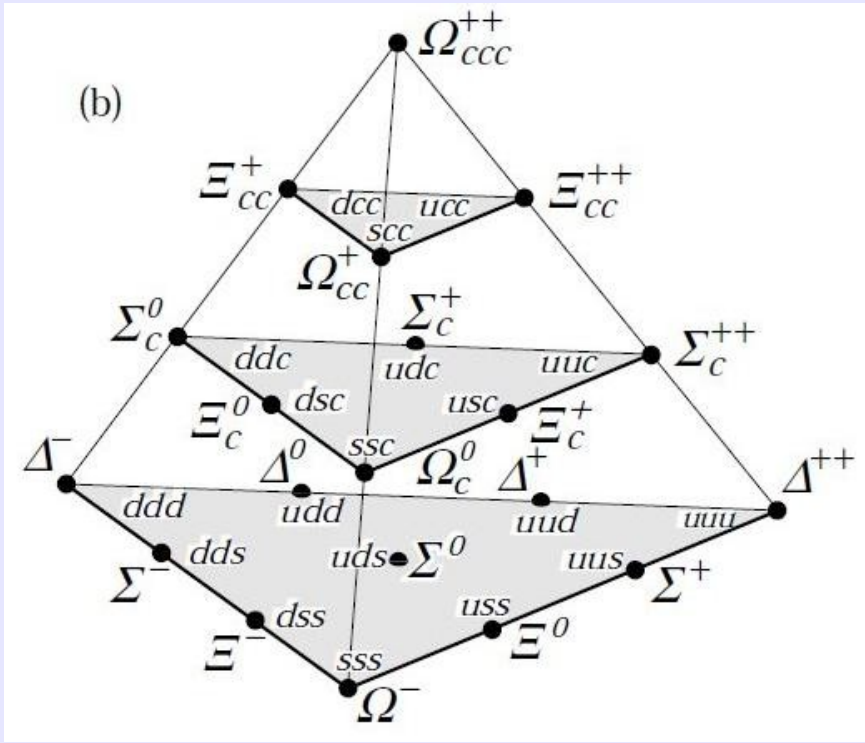
A total of 340 particles!!!

TODAY'S QUARK MODEL

Mesons with d u s c quarks



Baryons with d u s c quarks



More multiplets containing the b quark have been discovered

HOW DID LUIE INFLUENCE ME?

Style of leadership

Go, do it ! attitude

Think out of the box

Lina Galtieri and Luis Alvarez in 1977