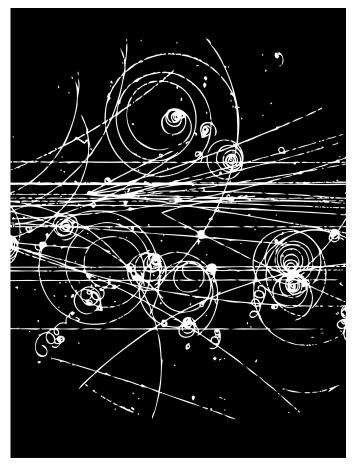
Hadron Spectroscopy



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UCAS Physics-department, June 20 – July 6, 2014

Summary (lecture 1)

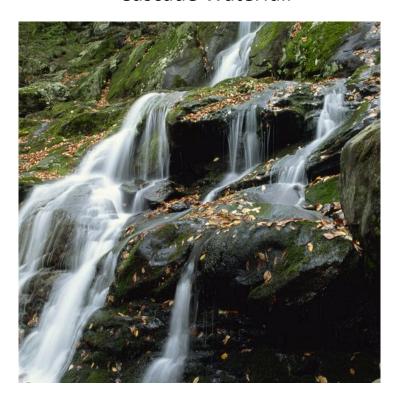
- The (expected) discovery of the π -meson and the (unexpected) discovery of the K-meson & Λ baryon in 1947 marked the beginning of hadron physics.
- The fact that K-mesons were produced in association with Λ-baryons led to the discovery of Strangeness, the 1st flavor. S is conserved in strong and electro-magnetic, but not in weak interactions.
- **•** Experiments showed that the spin and parity of the π , K and η mesons are all $J^P=0^-$.
- A matching set of meson resonances with $J^P=1^-$, the ρ , K^* and ω mesons, were found in bubble chamber experiments.
- A set of spin=3/2 baryon resonances, the $\Delta(1232)$, Y*(1385) (now called the $\Sigma(1385)$) and $\Xi(1530)$ was also discovered.
- Mesons come in octets; baryons come in octets and decuplets.

Lecture 2: Are hadrons made from more fundamental constituents?

But 1st: Why are Ξ baryons called "cascades?"

"cascade" ←English word for multi-tier waterfall

Cascade Waterfall



$$K^{-}p \rightarrow K^{0}\Xi^{0}\pi^{+}\pi^{-}$$

$$\pi^{+}\pi^{-} \longrightarrow \pi^{0}\Lambda^{0}$$

$$\gamma e^{+}e^{-} \longrightarrow \pi^{-}p$$



Elementary particle "Zoo" in 1963

Tables of Elementary Particles and Resonant States

←"wallet cards"

Matts Roos

Nordisk Institut for Teoretisk Atomfysik, Copenhagen, Denmark

Class	Symbol	Antiparticle	Isca	pin T.	,	" 🤇	stable	" "	ha	dron	S (1/ma)	Common decay modes	Branching ratios	References
/-	2"	-	å	-1	t	-2	1320.8 ± 0.4	9.46	(6/2m ₉)	1.4 (+0.6/-0.2)	3 × 10 ¹³	modes Δπ'	100	-
\	20	五+	2	91	,	-2	1316	9.43		3.9 (+1.4/-0.9) × 10 ⁻¹⁹		Aπ	100	1 2
	Σ~	-	1	-1	1+		1195.96 ± 0.30	8.57		(1.59 ± 0.05) × 10 ⁻¹⁰	3.4×10 ¹³	NT.		3, 4, 19
SI S	Σ0	Σ +		1 0	1+	-1	1191.5 ± 0.5	8.54		$10^{-11} > \tau > 10^{-22}$	10 ¹² > r'> 10	Αγ		3, 5, 19
Typerone	2+	Σ		0	30	-1	1189.40 ± 0.20	8.52		$(0.78 \pm 0.03) \times 10^{-10}$	1.65 × 10 ¹¹	pr ⁰	50.7 ± 2.3	
7 1		Σ-		-1	1	1	1100.10 11 0.20	0.00		(0.10 ± 0.00) X 10 -	1.09 × 10	$n\pi^+$	49.3 ± 2.3	0, 2, 10
	Λ^0		0	0	10	-1	1115.38 ± 0.10	7,991	-1.5 ± 0.5	$(2.57 \pm 0.30) \times 10^{-10}$	5.4×10 ¹¹	pa-	66(+4/-3)	6. 20
_		X*		0		1	1115.44 ± 0.32	7.991		(1.9 ± 1.0) × 10-11	4 × 10 ^{rs}	77.87	34(+3/-4)	
-1	nº		ì	-1	1+	0	939.507 ± 0.01	6.731	-1.9128	1013 ± 26	2.15 × 10 ⁸⁰	pt-7,	100	7, 8
Vucleons	p^+	71		121-22	1+	0	938.213 ± 0.01	6.722	2,792816 ±		60			7, 15
Nuol		p		-1		0			0.000034 -1.8 ± 1.2					10
-		-												
Suo	K+	K-	1/2	-01	0-	1 -1	493.98 ± 0.14	3.539	0	$(1.227 \pm 0.008) \times 10^{-9}$	2.60×10^{15}	$\mu^{+}\nu_{\mu}(\mu 2)$ $\pi^{+}\pi^{0}(\pi 2)$ $\mu^{+}\pi^{0}\nu_{\mu}(\mu 3)$ $e^{+}\pi^{+}\nu_{e}(e3)$ $\pi^{+}\pi^{+}\pi^{-}(\tau^{+})$ $\pi^{+}\pi^{0}\pi^{0}(\tau^{+})$	64.2 ± 1.3 18.6 ± 0.9 4.8 ± 0.6 5.0 ± 0.5 5.7 ± 0.3 1.7 ± 0.2	
Vienons	K^0	K1		-6	0-	1	497.9 ± 0.6	3.57	<0.01 he/mx	$K_2^{\bullet}(0.90 \pm 0.02) \times 10^{-0}$	$1.9 \times 10^{\mathrm{u}}$	π ⁺ π π ² π ²	69.4 ± 1.0 30.6 ± 1.0	11
		.		2		. 1			noy meg.	K ₁ 6.3(+1.6/−1.0) × 10 ⁻⁸	1.3×10^{15}	2+7-2°	8.7 ± 2.3 38 ± 7	12
										X 10 ·		#"6"F.	28.3 ± 5.9	
-												7+4-7, 7-4+7,	25.0 ± 5.9	
	g+		1	1	0-	0	139.58 ± 0.05	1	0	(2.547 ± 0.027) × 10 ⁻⁴	5.48 × 10°	μ*ν _κ	100	18
)	#°	π*		-1 0	0-	0	134.97 ± 0.05	0.967	0	$(1.05 \pm 0.18) \times 10^{-16}$	2.23×10^{7}	2γ	98.8	13, 22
+	μ-	-			à	-	105.65	000 701	(1.001162 ±	(2.210 ± 0.002) × 10 ⁻⁶	4.69 × 10 st	γe+e-	1.2	14
n		µ+			1		200.00	± 0.002	0.000005) e/2m _p	(e.ato ± 0.002) X 10*	1.00 € 100	6°9.0° µ	100	14
tons	6-	-	_		ì	-	0.510976 ala 0.000007	$1m_s$	(1.0011600 ± 0.000024)	00	- 09			7, 15

ELEMENTARY PARTICLES AND RESONANT STATES

meson resonances

							A (5.00A)		ME ANOU		.,	40000	
	78	8	g	, à	28120110	Ma		Full	Life-	Produ	netion		Decay
	Symbol	Charge	Isospin	Spin Parity G-parity	S	(MeV)	(m _e 1)	width P (MeV)	time I ⁻¹ (1/m _x s)	Process	(MeV)	Modes	Branel
	K*	-	> 3		1	1630 ± 100	11.7			x-p	3534	$(K_1^*\pi\pi)^-$ $(K_1^*\rho)^-$ $(K\pi\rho)^-$ others same, charge $+$	
	Xi.	0			0	1340 ± 70	9.6			<i>a</i> -p	2287	(orw)0 others	
	к)	٠			0	1275 :k 25	9.1			π ^p	2125	K ⁰ K̄ ⁰ K+K−	
	K**		-		1	1260	9.0			π-N		$K(n\pi)$	
	f		0	2 ++	0	1253 ± 20	9.0	100 ± 50	1.4	π⁻p	2070	44.	100
	K_b^{\bullet}	++	5 2		1	1150 ± 50	8.2			#"p	2250	K ⁰ π+π+ K ⁰ π-π-	
	X ₁ X ₁	-	1		0	1030 1040	7.5 7.4			2 ⁻ p	1620	x'-x'-x+x2 x+x-(xx)0	
	4	•	0	even ++	0	1040 ± 40	7.4			K~p	1780	$K_1^*K_1^*$ even number π 's	
	к1	*	0	odd	0	1020	7.3	< 3	>47	K⁻p	1760	$K!K!$ odd number π 's	
	ψι ψι ψι	*	2		0 0	990	7.2			π-p	1490	7"X" 7"X" 7"X"	100
	K_1^*		1/2	1 -	-1	888 ± 3	6.4	50 ± 10	2.8	$K^{\perp}p$	1074	K0π-	60 ±
k	\mathbb{K}_1^*	0			-1					K-p	1078	$K^-\pi^0$ $K^-\pi^+$ $\overline{K}^0\pi^0$	40 ±
	K_1^{\bullet}	+			1					π~p	1834	K ⁰ π ⁺ K ⁺ π ⁰	6'
	K_1^*	0			1					π ⁻ p	1657	$K^{+}\pi^{-}$ $K^{0}\pi^{0}$	0.
	91	0			0	885 ± 10	6.3			π-p	1284	#*#**	
	e.		0	1	0	781.1 ± 0.8	5.6	<12	>12	PP		### ##################################	0.12 ±
	ρ	-	1	1 ~ +	0	757 ± 5	5.4	120 ± 10	1.2	#"p	1029	4.44.44 4.44.44 4.44	>5
	ρ	٠			0	751 ± 6	5.4	110 ± 10	1.3	zN	1029	neutrals	94 (+6 6 (+40
	P2	٠		}	0	780	5.6	60	2.3	πN	1085	neutrals	`
	P1	٠			0	720	5.2	20	7	πN	975	neutrals	
	P	+			0					z+p	1066	x+x0	-
	ψ. Ψ. Κ.		2		0 0	760	5,4			a_b	1310 1055 1590	7"7" 7"8" 7"8"	100
	*:	+)	>1	1	730 ± 10	5.2	≤20	>7	x p	1485	K+=- K0=0	
		*	1 or 2	-	1 0	645 ± 25	4.5				810	(Kπ)+ π-π ⁰	-
	ō ō	+	1002		0	0169 ± 23	4.5			r p	010	ਜਾਜ* ਭਾਜਾ ਜਾਂਜ*	
	a a	+	1 or 2		0	625	4.5	<80	>1.7	pp		4,4,4,4,4 4,4,4,4,4	
	ψs ψs ψs	*	2	0 or 2	0 0 0	605 ± 25 580	4.3 4.2	75	1.9	z~p	1025 733 1235	π''π'' π''π'+ π''π'+	100
			1		0 0	564 ± 9 541 ± 18	4.0 3.9	<43	>3.2	#"p #"p	707 672	, #"#" #*#" #*#"	

baryon resonances

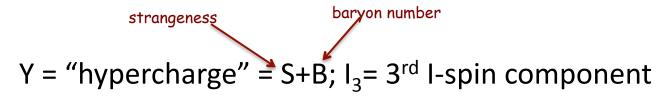
١.	Barvonie	Resonant States,	March	1963.	

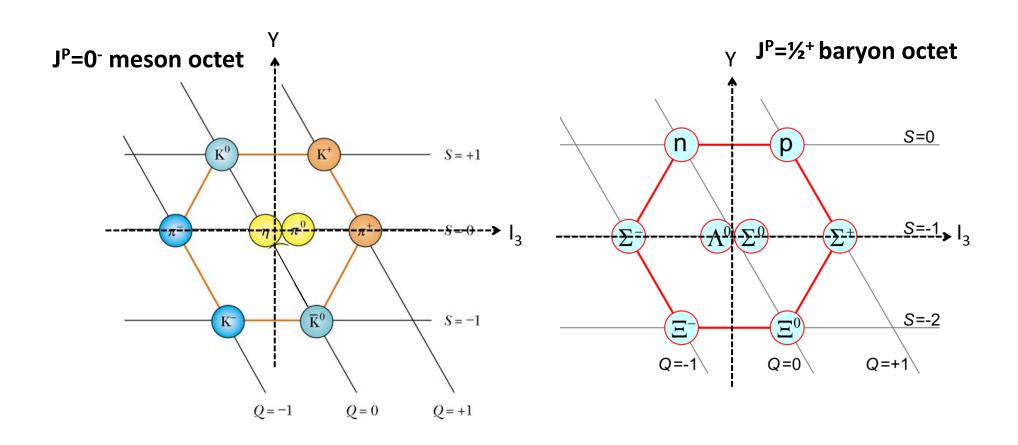
	75	0	-	1			T	PROTEST OF THE PARTY OF	The second second second	***	Prod	uction	I	Decay	The state of the s
	Symbol	Charge	Isospin	Spin	Parity	S	(MeV)	(m _* ±)	Full width P (MeV)	Life- time Γ^{-1} $(1/m_{v^{\pm}})$		(MeV)	Modes	Branching ratio (%)	Q (MeV)
	Y_{05}^{*}	0	0	5 or 2		-1	1815	13.0	120	1.16	K-p	1050	K⁻p others		383
	Y**	0				-1	1770 ± 100	12.7			π-p	2260	$Y_{12}^{\mathbf{x}_+}\pi^-$ $\Lambda\pi^+\pi^-$		245 376
	Y*	0				-1	1715	12.2			π ⁻ p	2185	$K^{o}n$	100	297
	Y**	4	0			-1	1680	12.0	<20	>7	K^-p	760	Αη		16
	Y**	*	1	3		-1	1660 ± 10	11.9	40 ± 10	3.5	К-р	715	$K^{a}p$ $(\Sigma \pi)^{+}$ $\Lambda \pi^{+}$ $\Lambda \pi^{+}\pi^{a}$ $\Sigma^{a}\pi^{b}\pi^{+}$	~10 30 25 20 15	224 333 405 270 188
	Y_2^*		1 or 2			-1	1550 ± 20	11.1	125	1.75	т-р	1770	Σπ	100	227-230
X *	Et Et	0	1/2	2	+	-2 -2	1533 ± 3	10.98	≤7	≥20	K^-p	1512 1521	Ξ π° Ξ°π – Ξ π+	40 60 100	78 82 73
	Y_{6a}^*	Đ	0	2	-	-1	1520 ± 3	10.89	16	8.7	<i>K</i> ~ <i>p</i>	395	$(\overline{K}N)^0$ $(\Sigma\pi)^0$ $\Lambda\pi^+\pi^-$	33 56 11	82-88 184-193 126
	Y_0^*		0			-1	1404.7 ± 0.4	10.1	<1.4	>100	K⁻p	445	$(\Sigma \pi)^0$ $\Lambda \pi \pi$		69-78 10-20
γ*	Y ₁₀ Y ₁₈ Y ₁₉	a +,	1	3 or 3	+	-1 -1 -1	1385 ± 5	9.92	50 ± 10	2.8	К~р	408 395 408	$(\Sigma \pi)^-$ $\Lambda \pi^-$ $(\Sigma \pi)^{i}$ $\Lambda \pi^{j}$ $(\Sigma \pi)^+$ $\Lambda \pi^{+}$	1(±3) 90(±3) 1(±3) 99(±3)	54 130 49-58 135 53-61 130
	N_z^*		3 2			0	2360 ± 25	16.9	200 ± 25	0.7	π ⁺ p	2510	πN others		1280
	N_I^*		1/2			0	2190 ± 25	15.7	200 ± 20	0.7	- -p	2080	#N others		1110
	Z_3^*	a	3,	>3		0	1920 ± 20	13.8	15	9	$\pi^-(A)$		K ⁰ Λ (K Σ) ⁰		307 231
	N_{st}^*		ğ	ž		0	1900	13.6	200	0.7	$\pi^{-}(A)$.	1440	πN ΚΣ	30 <4	820 215
	N_{11}^{*}		1/2	1/2	+	0	1690	12.1			π ⁻ p	1030	πN	100	612
	N_{10}^{*}		1/2	2	+	0	1683 ± 5	12.06	80	1.7	π~p	1020	πN $K\Lambda$ others	80 <2 >18	605 74
	Z_1^*	0	.3	>1		0	1650 ± 20	11.8	<7	>20	$\pi^-(A)$		K°A	100	38
	N_{1s}^{*}		1/2	3	- 1	0	1517 ± 3	10.87	60	2.3	' πp	731	πN others		439
D	N*18 N*19 N*19 N*28	+	9	32	+	0	1237	8.86	90 ± 20	1.6	πN	303	π ⁻ n π ⁻ p π ^a n π ^a p π ⁺ n π ⁺ p	100	158 159 163 164 158 159

"non-strange:" n, p, p, r, ...

"strange:" L, S, K, K*, ...

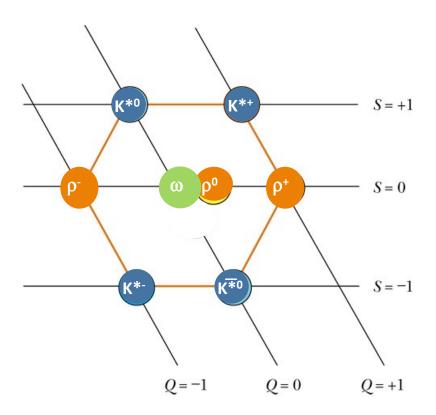
Meson and Baryon Octets



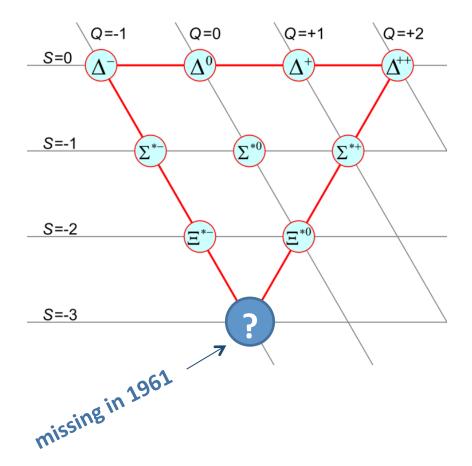


resonances

J^P=1⁻ vector meson octet



JP=3/2+ baryon "decuplet"

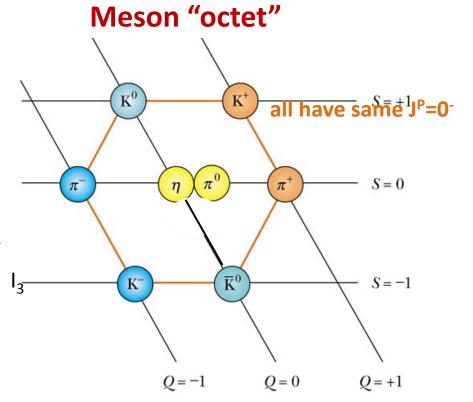


1st attempts at Classification

Gell-Mann, Nakano, Nishijima realized that electric charge (Q) of all particles could be related to isospin (3rd component), Baryon number (B) and Strangeness (S):

$$Q = I_3 + (S + B)/2 = I_3 + Y/2$$
hypercharge (Y) = (S+B)

Interesting patterns emerge when I₃ is plotted vs. Y

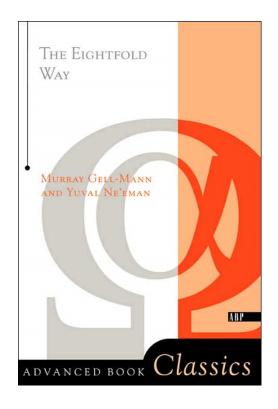


1961: Gell-Mann, Nishijima & Nee'man: The Eightfold Way









The Eightfold Way appears in the Buddhist teaching: "This is the noble truth that leads to the cessation of pain. This is the noble eightfold way. . ."

Octets (and decuplets) are representations of the SU(3) Lie group:

SU(2) group: Angular Momentum in QM

Pauli Matrices

$$\sigma_1 = \sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_2 = \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

$$\sigma_3 = \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Representations:

$$\begin{pmatrix} +\frac{1}{2} \\ 0 \end{pmatrix} \begin{pmatrix} 0 \\ -\frac{1}{2} \end{pmatrix} \qquad \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad \dots$$

$$Spin=1/2$$

$$Spin=1$$

SU(3) group: Generalization of SU(2)

Gell-Mann Matrices

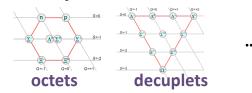
$$\lambda_{1} = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \qquad \lambda_{5} = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix}$$

$$\lambda_{2} = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \qquad \lambda_{6} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$\lambda_{3} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \qquad \lambda_{7} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix}$$

$$\lambda_{4} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \qquad \lambda_{8} = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

Representations:



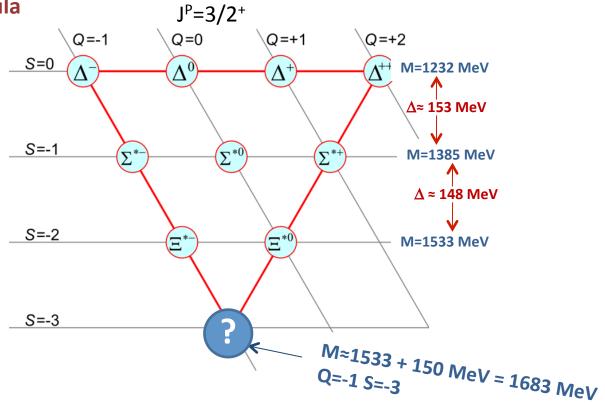
SU(3) prediction for the Ω^{-} mass





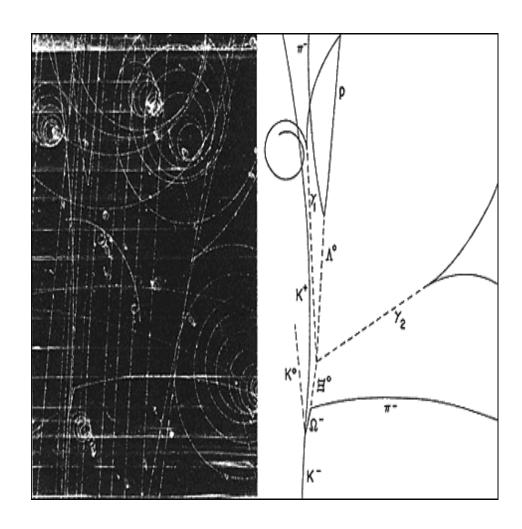
Each unit of Strangeness increases M by 150 MeV

Gell-Mann Okubo mass formula

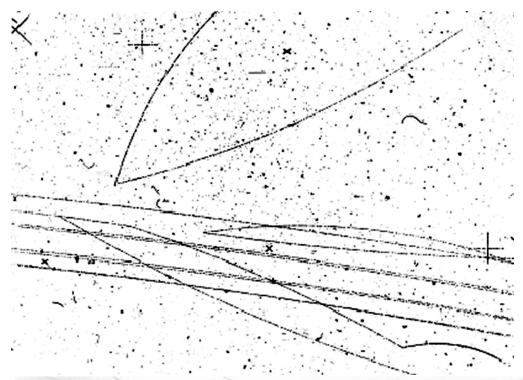


1965: Ω discovery

1965: the Ω^- was discovered at the Brookhaven Lab in NY. USA with S=-3 & M = 1672 MeV, near the Gell-Mann/Okubo prediction



Ω seen at CERN too



Omega minus produced by 4.2GeV K-

This remarkable event shows the production and decay of an omega-minus by a 4.2 GeV beam K particle in the CERN 2 metre hydrogen bubble chamber.

In this event there are two vees: one comes from the primary interaction while the other comes from the kink. (You can check this by printing off the event and then following back - with a ruler - the line joining the point where the vee tracks cross to the vee decay point. It clearly points to the kink.)

The track from the kink must be a K^- or a π^- , depending on whether the parent particle was an Ω^- or a π^- . This track itself kinks, quite considerably, telling us that it is a K^- . (The mass of a μ is so close to that of a π that it could not provide the energy to produce such a sharp kink.)

So, without any measurements, we have identified an Ω^- decaying to $\Lambda^{\circ}K^-$.

A measurement of the event reveals that the reaction is

another important discovery occurred at about the same time

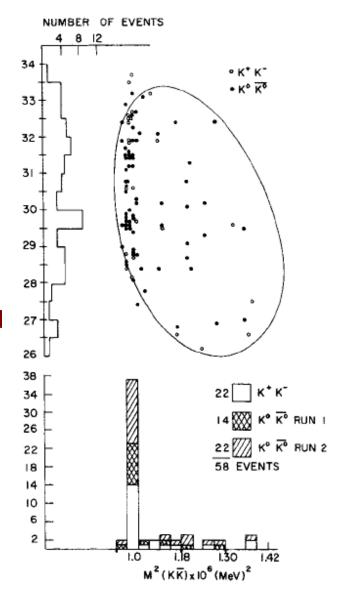
Discovery of the $\phi(1020)$

-- more important than the Ω^{-} ? --

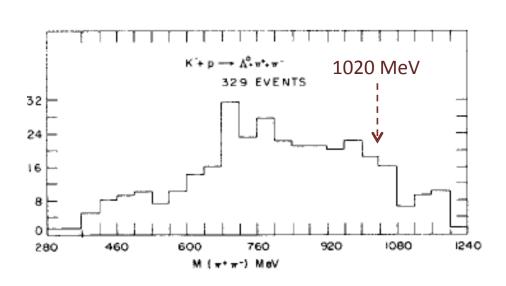
Phys.Rev.Lett. 10, 134 (1963)

$$K^{-}p \rightarrow K^{0}\overline{K}^{0}n \iff P_{K^{-}} = 2.23 \text{ GeV}$$

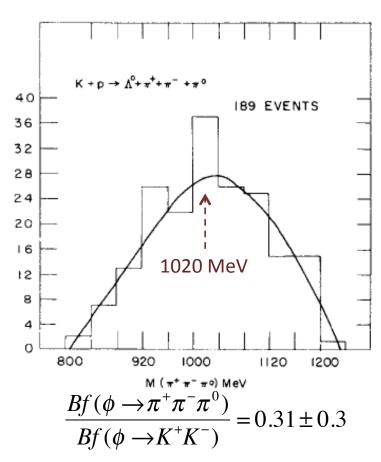
 $K^{-}p \rightarrow K^{+}K^{-}n$



no $\phi \rightarrow \pi^+\pi^-$; $\phi \rightarrow \pi^+\pi^-\pi^0 < \phi \rightarrow K^+K^-$



For J=1⁻ and I=0. $\phi \rightarrow \pi^+\pi^-$ is forbidden



 $\phi \rightarrow \pi^+ \pi^- \pi^0$ is allowed and has lots of phasespace. Why is it suppressed relative to $\phi \rightarrow K^+ K^-$, which has tiny phase-space?

what's the difference between the $\omega(782)$ and the $\phi(1020)$?

Partial width:
$$\Gamma(X \to Y + Z) \equiv Bf(X \to Y + Z) \times \Gamma_{\text{total}}^{X}$$

This is what theorists calculate --

same quantum
$$\Gamma(\omega(782) \to \pi^+\pi^-\pi^0) \approx 7.5 \text{ MeV}$$
 wis 10 × larger numbers $\Gamma(\phi(1020) \to \pi^+\pi^-\pi^0) \approx 0.65 \text{ MeV}$

φ has more phase space

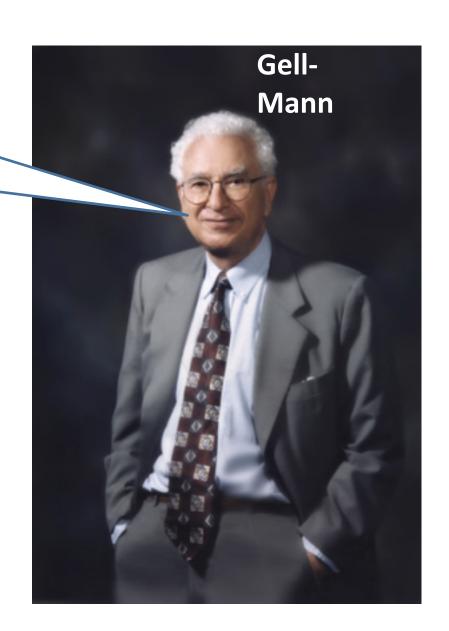
"totalitarian" principle

极权主义

What isn't forbidden, is mandatory

不被禁止的都是强制性的

What enhances $\phi \rightarrow K^+K^- \&$ suppresses $\phi \rightarrow \pi^+\pi^-\pi^0$?



early attempts to identify hadron constituents

1st attempt to identify hadron constituents: Fermi-Yang

Fermi & Yang in 1949 (7 years before \bar{p} discovery):

if $N\overline{N}$ potential is attractive, N & \overline{N} could bind to form a π -meson.

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, Vol. 76, No. 12

pg 1739

DECEMBER 15, 1949

Are Mesons Elementary Particles?

E. Fermi and C. N. Yang*

Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received August 24, 1949)

The hypothesis that π -mesons may be composite particles formed by the association of a nucleon with an anti-nucleon is discussed. From an extremely crude discussion of the model it appears that such a meson would have in most respects properties similar to those of the meson of the Yukawa theory.

$$egin{aligned} \left|\pi^{+}
ight> = \left|p
ight> \left|\overline{n}
ight> \ \left|\pi^{0}
ight> = rac{1}{\sqrt{2}} \left(\left|p
ight> \left|\overline{p}
ight> + \left|n
ight> \left|\overline{n}
ight>
ight) \ \left|\pi^{-}
ight> = \left|n
ight> \left|\overline{p}
ight> \end{aligned}$$

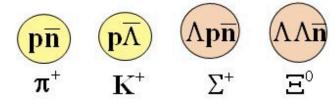
2nd attempt to identify hadron constituents: Sakata

1956 Sakata Model

All the hadrons are composite states of

 $\mathbf{p}, \mathbf{n}, \Lambda$

: Fundamental Triplet





Courtesy of Sakata Memorial

Shoichi Sakata 1911-1970

It seems to me that the present state of the theory of new particles is very similar to that of the atomic nuclei 25 years ago. Supposing that the similar situation is realized at present, I proposed a compound hypothesis for new unstable particles to account for Nishijima-Gell-Mann's rule.

S. Sakata, Prog. Theor. Phys. **16** (1956), 686. **1959 Ikeda, Ogawa, Ohnuki**

II(3) symmetry of the Sakata Moel

Sakata's Notebook

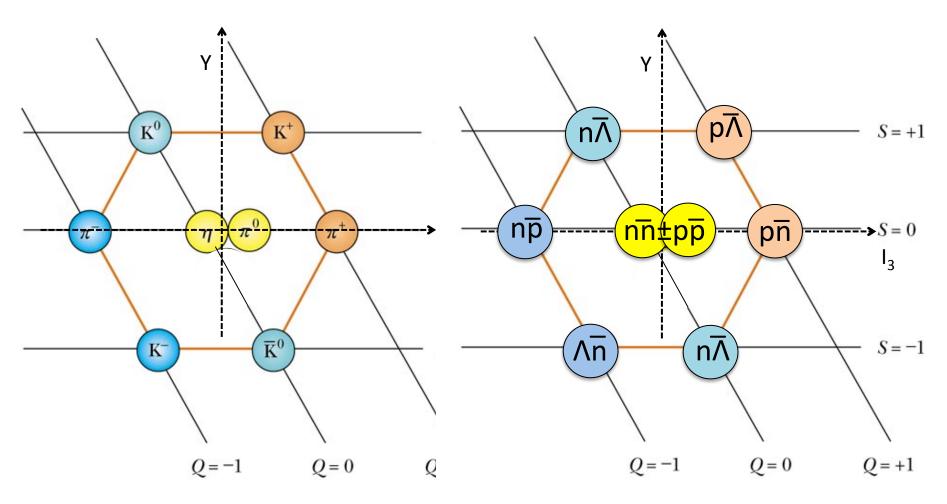
Fermi-Yana naner

			Fermi-T Wenge	ang P. F	P. R. 76, 1739, 1949			
A possible model for the new unitable particles.	. η ^{±,0} =	(P+N P+P() N+P		Parity	Isospin	$ \eta \left(\begin{array}{c} Q = I_z + I_z \\ O & 0 \end{array} \right) $		
切取I. 素粒子として baryon family に PN VO 9三種を保定する	. Q+,0	(P+Ve	i i	1	- 0 - 4	0		
lepton family 1= et, V, pt E 战定了3.	Ct.º	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \		O 5 +	±	1 1 0		
TI-on family, baryon family, heavy fragment, muleus 17 P,N, X° B 20 anti-particle o	Ν	PN		± A	立	1 0 1		
集合体としてみちいく. 1名定皿 (P,N)は(き,き)のて-spinをもつ	N Vo	N, P		古七	6 0	0-1 4		
VO 1+ 0 or t-spein toto	ν° Σ+•-	18+10+	Y0	支车) °	0 11 1		
(但 Spin H 共n 主)		PtPt	V-R-	12 1	2 0	. 1		
(ii) Strong Interaction: to charge a Conserv. (iii) Strong Interaction: to 113	= E YOU	(VO TV	0+ P	± 548	1			
(111) Weak Interaction 2°18 $\Delta I = \pm$	X .	v°+7 ≠ ∠P+		P ₂ /				

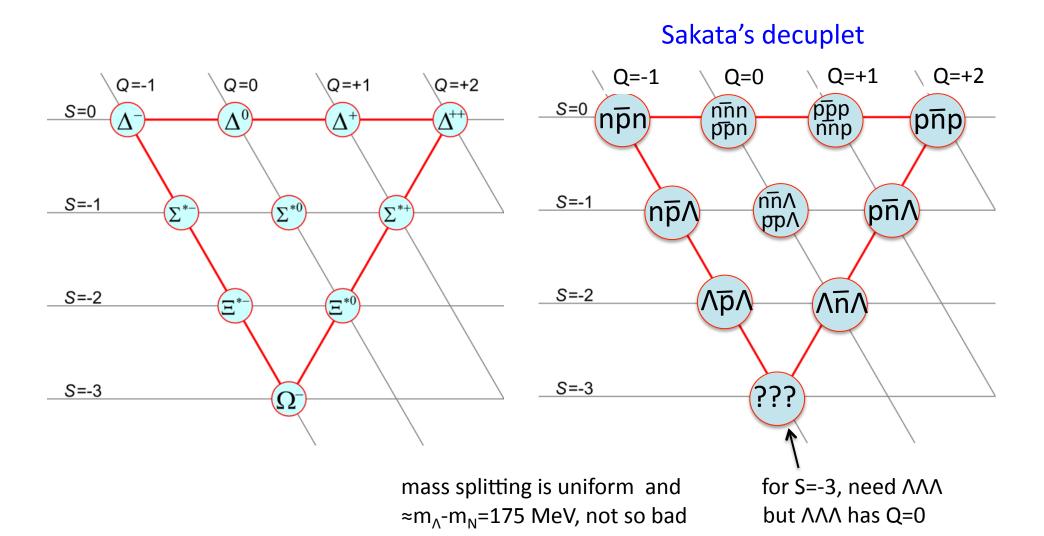
Sakata calls the Λ^0 and the $\,\,K$ mesons by their old names: $V^0,\,\theta^{+,0}$ and $\tau^{+,0}$

Sakata model produce the meson octets

J^P=0⁻ meson octet

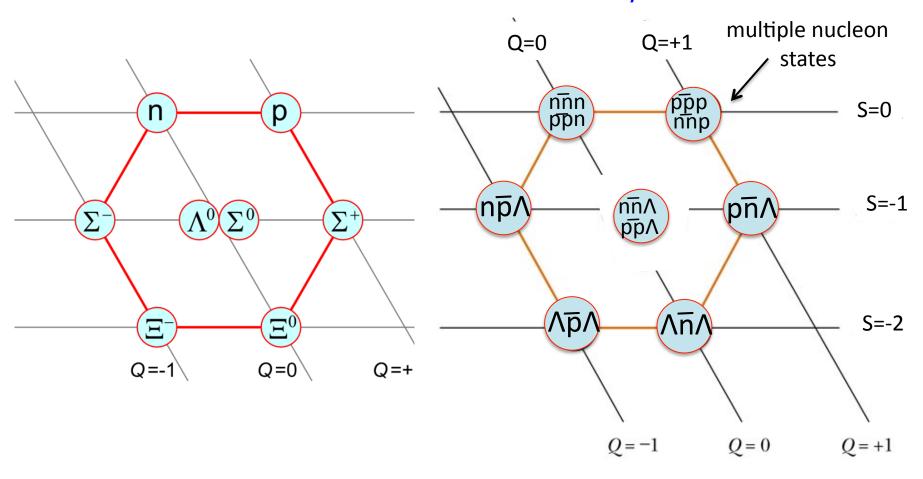


but the baryon decuplet has problems

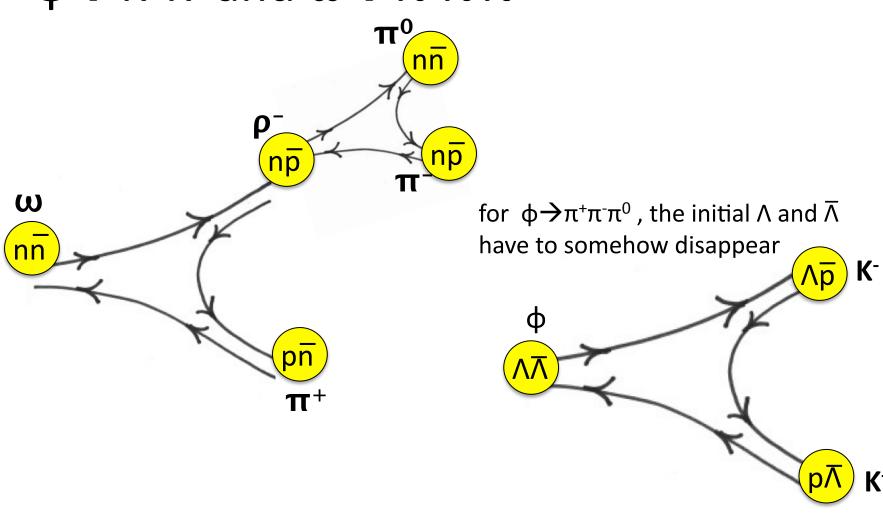


Sakata's baryon octet is a little peculiar

Sakata's baryon octet

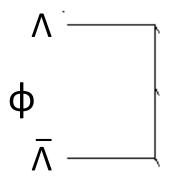


Sakata also explains why $\rightarrow K^+K^-$ and $\omega \rightarrow \pi^+\pi^-\pi^0$

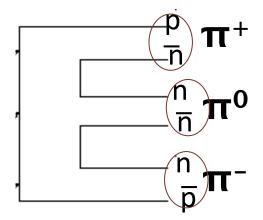


OZI suppression

initial state



initial state



processes in which there are no constituent lines connecting the initial &final states are suppressed

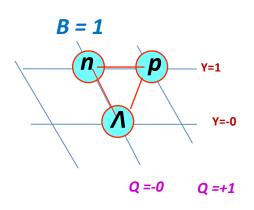
Comments on the Sakata model

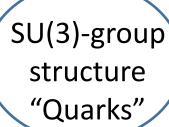
- •It reproduces the meson octets
- •it can explain the φ-ω puzzle
- •It can produce baryon octets and decuplets, but with some S=-3 state charge shifted by ΔQ =+1
- •It treats the p. n and Λ as special, for no obvious reason
- •It contains some truth but it is not the whole story

Quarks (Aces?)

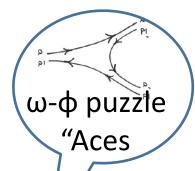




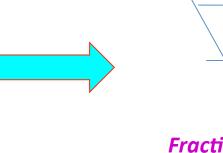


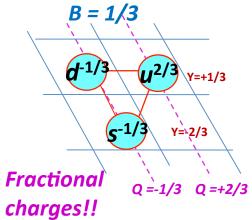




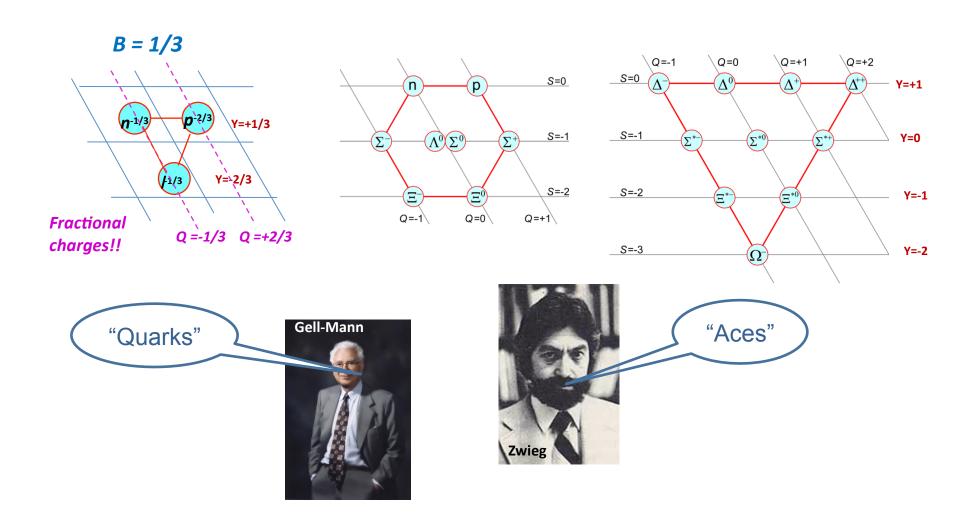






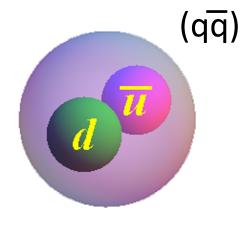


1964: triplet = the most fundamental representation of SU(3)



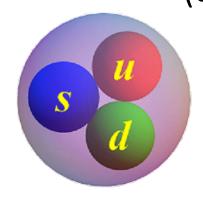
Textbooks: Quark-Parton-Model

mesons = quark-antiquark



$$\pi^- = (d\overline{u})$$

baryons = quark-quark-quark (qqq)

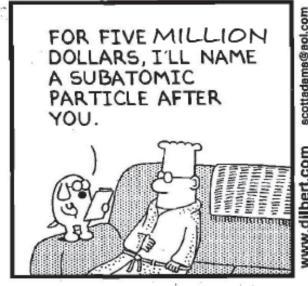


$$\Lambda = (uds)$$

Fabulously successful

Quarks are probably the most well known particle physics quantity among the general public

DILBERT



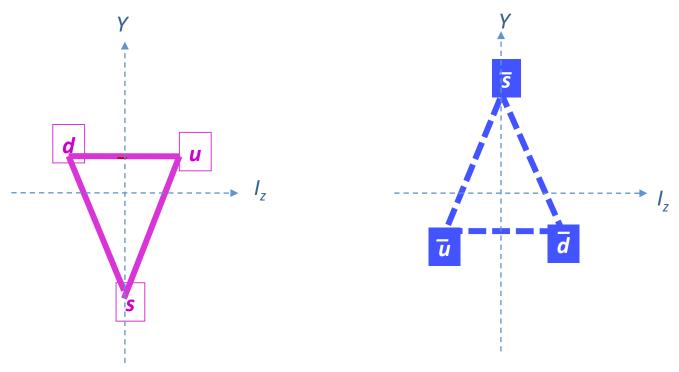




Google Search: quark: 25,500,000 results

Yao Ming: 17,300,000 results

Quarks & Antiquarks in I_z -Y space

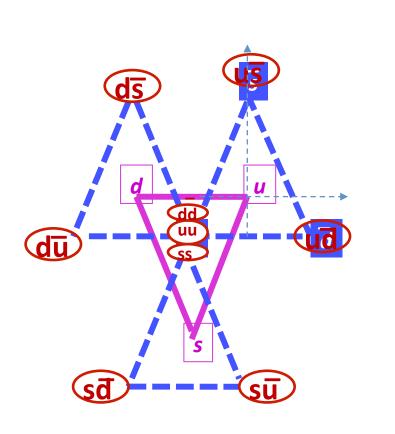


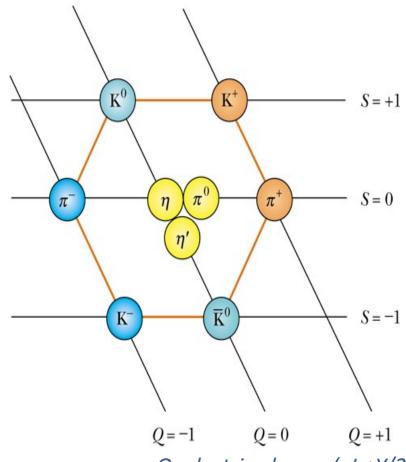
 $I_{z=}z$ component of Isospin

Y=hypercharge (=Baryon# + Strangeness)

quarks have Baryon#=⅓

Make mesons from quark-antiquark



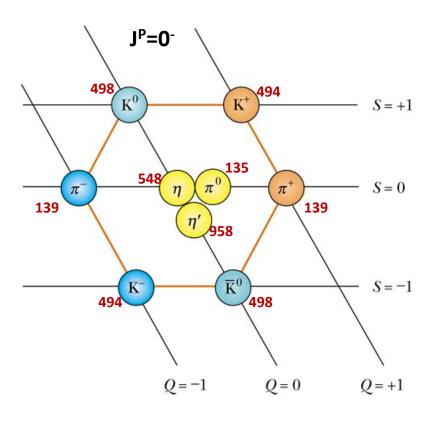


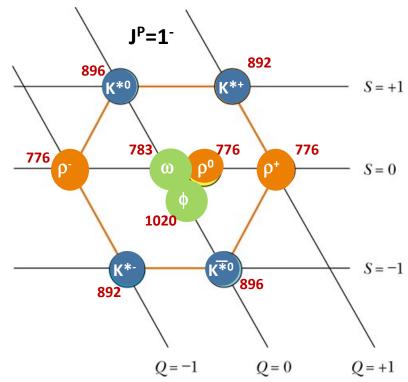
Q=electric-charge (= I_z +Y/2)

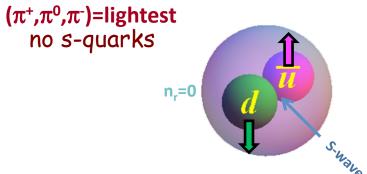
9 states: $3 \otimes \overline{3} = 1 \oplus 8$

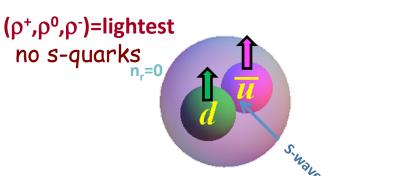
SU(3) singlet + SU(3) octet

Ground state mesons







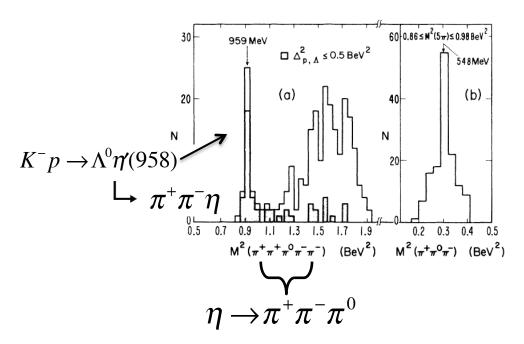


Discovery of the η' meson

Phys.Rev.Lett. 12, 527 (1964)

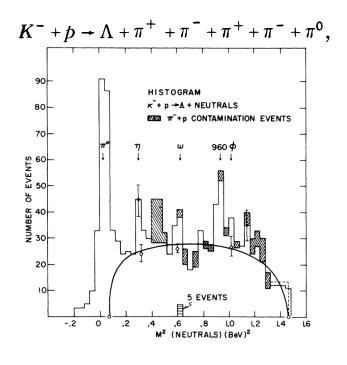
Berkeley 72" BC

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



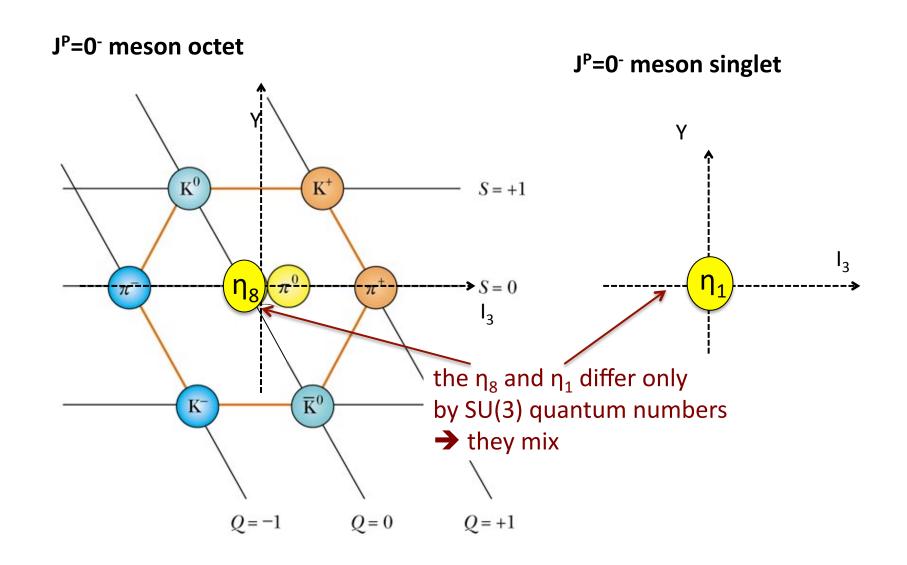
Phys.Rev.Lett. 12, 546 (1964)

Brookhaven 80" BC



M=957.8 ± 1 MeV $\Gamma = 0.20 \pm 0.01$ MeV $J^P = 0^-$

meson "nonet" = octet + singlet



η-η'mixing

SU(3) has two η -mesons, an "octet" η_8 , and a singlet η_1 , where:

$$\eta_1 = \frac{1}{\sqrt{3}} \left(u\overline{u} + d\overline{d} + s\overline{s} \right)$$

$$\eta_8 = \frac{1}{\sqrt{6}} \left(u\overline{u} + d\overline{d} - 2s\overline{s} \right)$$

However, SU(3) is a broken symmetry, so η_1 an η_8 "mix". Thus the physical η and η' mesons are each mixtures of η_1 and η_8 :

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\theta_p & \sin\theta_p \\ -\sin\theta_p & \cos\theta_p \end{pmatrix} \begin{pmatrix} \eta_1 \\ \eta_8 \end{pmatrix},$$

where θ_P is the "pseudoscalar mixing angle." The range of of allowed values is:

$$\theta_P = -11^o \Leftrightarrow -25^o$$

For θ_p =-9.7°, the η & η ' have same $s\overline{s}$ and $(u\overline{u}+d\overline{d})/\sqrt{2}$ content (with opposite relative sign).

ω-φ mixing

The ω and φ also mix, but in this case θ_V , the "vector mixing angle" is large and positive:

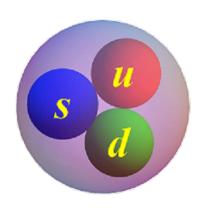
$$\theta_{\rm V} \approx 37^{\rm o}$$

this is very close to the "ideal" mixing angle

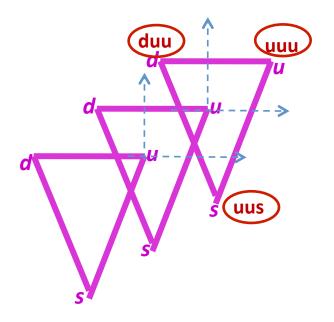
$$\theta_V^{\text{ideal}} = \arctan(\frac{1}{\sqrt{2}}) = 35.3^\circ$$

in which case the ϕ -meson would be 100% $s\overline{s}$ while the ω -meson would be 100% $(u\overline{u}+d\overline{d})/\sqrt{2}$. In fact the $s\overline{s}$ content of the ω is about 3% of $(u\overline{u}+d\overline{d})/\sqrt{2}$.

How about the baryons=qqq model?

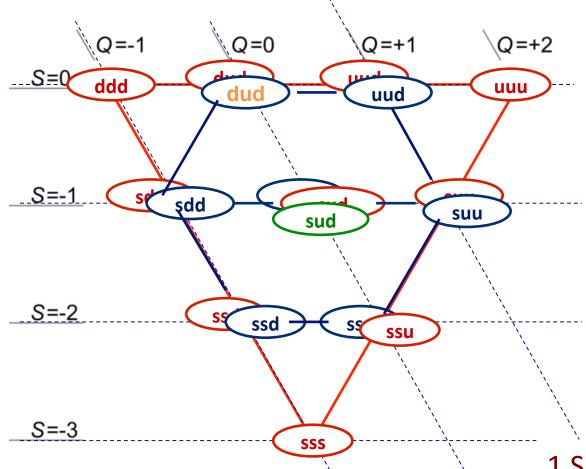


Make baryons from 3 quarks



HW: Finish the procedure

Answer

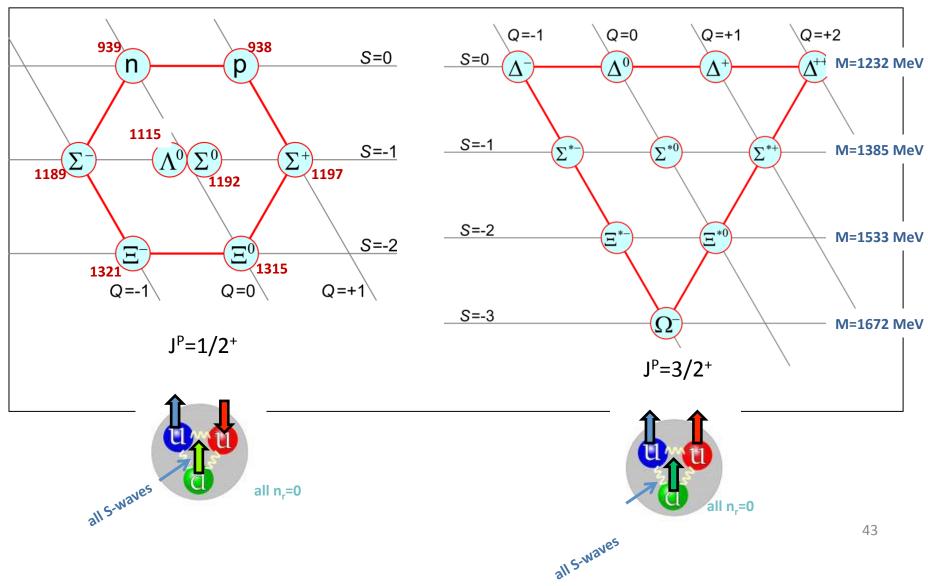


27 states: $3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$ +2 SU(3) octets

1 SU(3) decuplet

+1 SU(3) singet

Ground state Baryons



Summary (lecture 2)

- The fractionally charged quark model does a good job at explaining then patterns and properties of the ground state mesons and baryons.
- The $q\bar{q}$ =mesons and qqq=baryon prescriptions work well for the lowest-lying mesons & baryons, but fail otherwise

Discussion/HW items

Why is $\phi(1020) \rightarrow \pi\pi$ forbidden?

In octet-singlet meson mixing there are two extreme cases:

- --in one, called "Ideal mixing," one of the physical mesons is purely $s\overline{s}$, while the other is purely $(u\overline{u}+d\overline{d})/\sqrt{2}$.
- --in the other extreme, the two physical mesons have equal $s\overline{s}$ and $(u\overline{u}+d\overline{d})/\sqrt{2}$ content, with opposite relative sign.

Show that ideal mixing occurs when the mixing angle θ =35.3° and the equal $s\overline{s}$ -content cases occurs when θ =-9.7°.