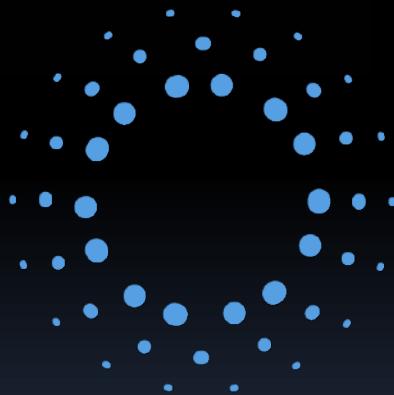


Aventuras em Física Teórica

# Introdução à Física de Partículas

Ricardo D'Elia Matheus



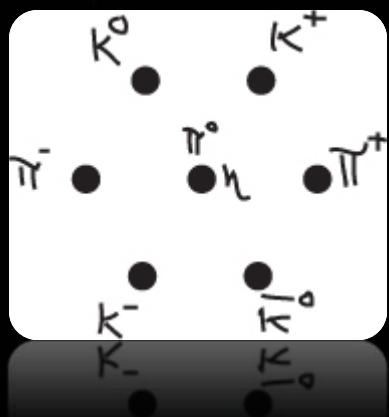
**IFT - UNESP**  
INSTITUTO DE FÍSICA TEÓRICA

# Os Hádrons e a QCD

<b>p</b>	<b>K<sup>+</sup></b>	<b>Ξ<sup>-</sup></b>	<b>Δ<sup>++</sup></b>	<b>Σ<sup>*0</sup></b>
<b>PROTON</b> massa: 938 MeV  spin-½ Q = +1 S = 0  descoberta: 1919	<b>KAON (K PLUS)</b> massa: 494 MeV  spin-0 Q = +1 S = +1  descoberta: 1947	<b>Ξ MINUS</b> massa: 1322 MeV  spin-½ Q = -1 S = -2  descoberta: 1952	<b>DELTA DOUBLE PLUS</b> massa: 1231 MeV  spin-¾ Q = +2 S = 0  descoberta: 1954	<b>SIGMA STAR ZERO</b> massa: 1384 MeV  spin-¾ Q = 0 S = -1  descoberta: 1960
<b>n</b>	<b>π<sup>-</sup></b>	<b>Σ<sup>+</sup></b>	<b>Δ<sup>+</sup></b>	<b>Σ<sup>*+</sup></b>
<b>NEUTRON</b> massa: 940 MeV  spin-½ Q = 0 S = 0  descoberta: 1932	<b>PION (PI MINUS)</b> massa: 140 MeV  spin-0 Q = -1 S = 0  descoberta: 1947	<b>SIGMA PLUS</b> massa: 1189 MeV  spin-½ Q = +1 S = -1  descoberta: 1953	<b>DELTA PLUS</b> massa: 1235 MeV  spin-¾ Q = +1 S = 0  descoberta: 1954	<b>SIGMA STAR PLUS</b> massa: 1383 MeV  spin-¾ Q = +1 S = -1  descoberta: 1960
<b>π<sup>+</sup></b>	<b> KAON (KBAR ZERO)</b>	<b>Σ<sup>-</sup></b>	<b>Σ<sup>0</sup></b>	<b>η</b>
<b>PION (PI PLUS)</b> massa: 140 MeV  spin-0 Q = +1 S = 0  descoberta: 1947	<b>KAON (KBAR ZERO)</b> massa: 498 MeV  spin-0 Q = 0 S = -1  descoberta: 1947	<b>SIGMA MINUS</b> massa: 1197 MeV  spin-½ Q = -1 S = -1  descoberta: 1953	<b>SIGMA ZERO</b> massa: 1193 MeV  spin-½ Q = 0 S = -1  descoberta: 1956	<b>ETA</b> massa: 548 MeV  spin-0 Q = 0 S = 0  descoberta: 1961
<b>K<sup>-</sup></b>	<b>π<sup>0</sup></b>	<b>Δ<sup>-</sup></b>	<b>Ξ<sup>0</sup></b>	<b>Ξ<sup>*-</sup></b>
<b>KAON (K MINUS)</b> massa: 494 MeV  spin-0 Q = -1 S = -1  descoberta: 1947	<b>PION (PI ZERO)</b> massa: 135 MeV  spin-0 Q = 0 S = 0  descoberta: 1949	<b>DELTA MINUS</b> massa: 1232 MeV  spin-¾ Q = -1 S = 0  descoberta: 1954	<b>XI ZERO</b> massa: 1315 MeV  spin-½ Q = 0 S = -2  descoberta: 1959	<b>XI STAR MINUS</b> massa: 1535 MeV  spin-¾ Q = -1 S = -2  descoberta: 1962
<b>K<sup>0</sup></b>	<b>Λ</b>	<b>Δ<sup>0</sup></b>	<b>Σ<sup>*-</sup></b>	<b>Ξ<sup>*0</sup></b>
<b>KAON (K ZERO)</b> massa: 498 MeV  spin-0 Q = 0 S = +1  descoberta: 1947	<b>LAMBDA</b> massa: 1116 MeV  spin-½ Q = 0 S = -1  descoberta: 1951	<b>DELTA ZERO</b> massa: 1231 MeV  spin-¾ Q = 0 S = 0  descoberta: 1954	<b>SIGMA STAR MINUS</b> massa: 1387 MeV  spin-¾ Q = -1 S = -1  descoberta: 1960	<b>XI STAR ZERO</b> massa: 1532 MeV  spin-¾ Q = 0 S = -2  descoberta: 1962

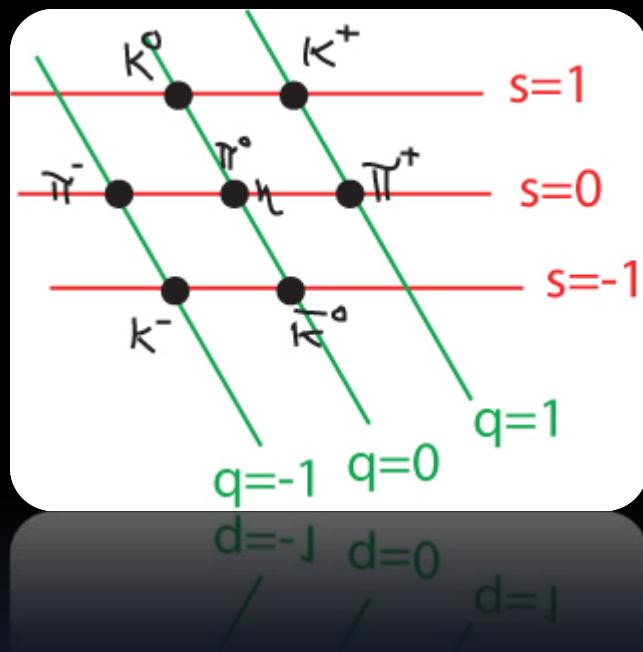
# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):



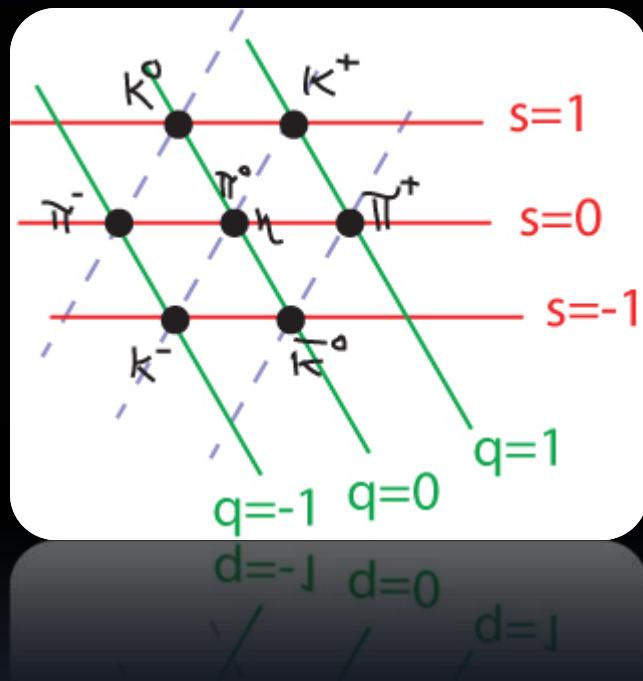
# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):



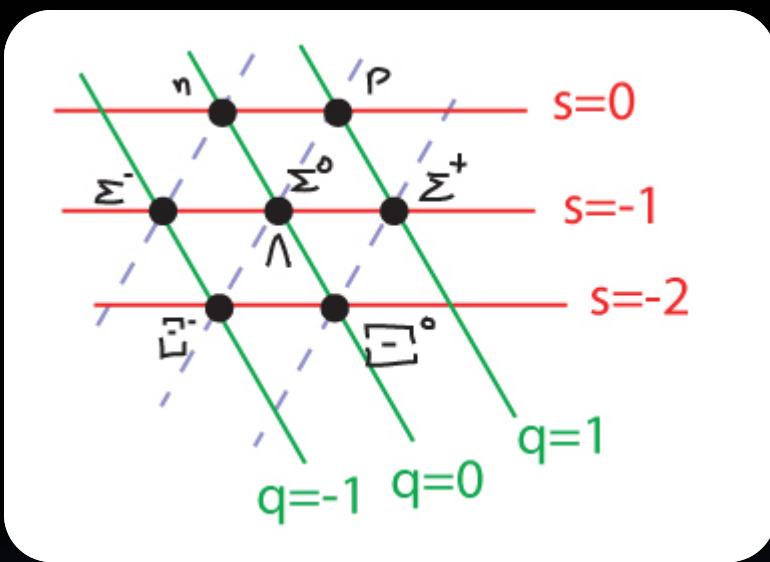
# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):



# Os Hádrons e a QCD

Multipletos (octeto de bárions, spin  $\frac{1}{2}$ ):



$\sim 940$  MeV

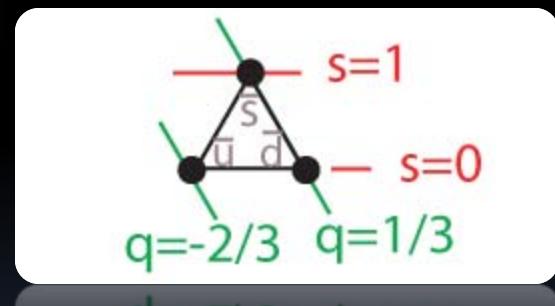
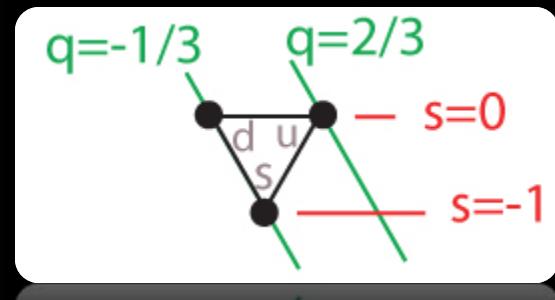
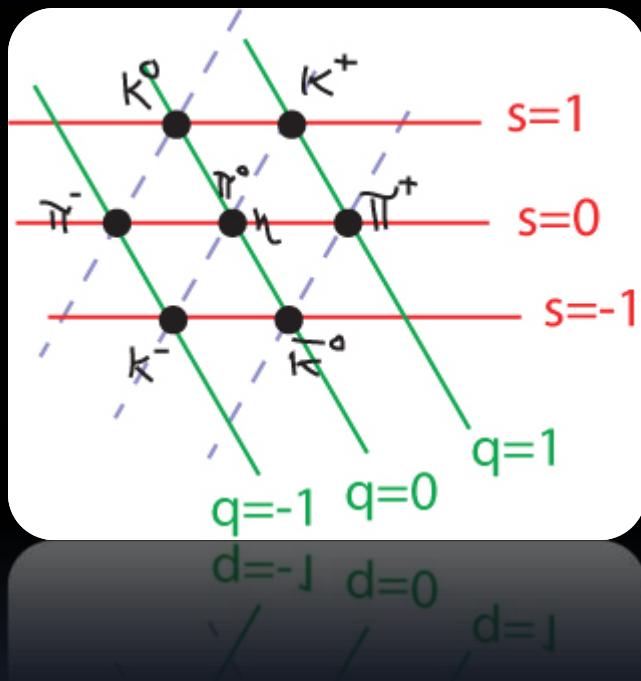
$\sim 1200$  MeV

$\sim 1320$  MeV

$d=-1$     $d=0$     $d=1$

# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):



# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):

$q\bar{q}$	$u\bar{u}$	$u\bar{d}$	$u\bar{s}$	$d\bar{u}$	$d\bar{d}$	$d\bar{s}$	$s\bar{u}$	$s\bar{d}$	$s\bar{s}$
<b>Q</b>	0	+1	+1	-1	0	0	-1	0	0
<b>S</b>	0	0	+1	0	0	+1	-1	-1	0
<b>Símbolo da partícula</b>	$\eta, \pi^0$	$\pi^+$	$K^+$	$\pi^-$	$\eta, \pi^0$	$K^0$	$K^-$	$\bar{K}^0$	$\eta$

# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):

$q\bar{q}$	$u\bar{u}$	$u\bar{d}$	$u\bar{s}$	$d\bar{u}$	$d\bar{d}$	$d\bar{s}$	$s\bar{u}$	$s\bar{d}$	$s\bar{s}$
<b>Q</b>	0	+1	+1	-1	0	0	-1	0	0
<b>S</b>	0	0	+1	0	0	+1	-1	-1	0
<b>Símbolo da partícula</b>	$\eta, \pi^0$	$\pi^+$	$K^+$	$\pi^-$	$\eta, \pi^0$	$K^0$	$K^-$	$\bar{K}^0$	$\eta$
baseado no J	J	J	J	J	J	J	J	J	J

Combinação de  $u\bar{u}$  e  $d\bar{d}$

# Os Hádrons e a QCD

Multipletos (octeto de mésons, spin 0):

$q\bar{q}$	$u\bar{u}$	$u\bar{d}$	$u\bar{s}$	$d\bar{u}$	$d\bar{d}$	$d\bar{s}$	$s\bar{u}$	$s\bar{d}$	$s\bar{s}$
<b>Q</b>	0	+1	+1	-1	0	0	-1	0	0
<b>S</b>	0	0	+1	0	0	+1	-1	-1	0
<b>Símbolo da partícula</b>	$\eta, \pi^0$	$\pi^+$	$K^+$	$\pi^-$	$\eta$	$\pi^0$	$K^0$	$K^-$	$\bar{K}^0$

partículas  
polo das

Combinação de  $u\bar{u}$  e  $d\bar{d}$

Combinação de  $u\bar{u}$ ,  $d\bar{d}$  e  $s\bar{s}$

$\eta'$  é outra combinação!

# Os Hádrons e a QCD

Multipletos (octeto de bárions, spin  $\frac{1}{2}$ ):

qqq	uuu	uud	udd	ddd	uus	uds	dds	uss	dss	sss
<b>Q</b>	+2	+1	0	-1	+1	0	-1	0	-1	-1
<b>S</b>	0	0	0	0	-1	-1	-1	-2	-2	-3
Bárions de spin-1/2		p	n		$\Sigma^+$	$\Sigma^0$ $\Lambda$	$\Sigma^-$	$\Xi^0$	$\Xi^-$	

21-fíndis  
de sondas

# Os Hádrons e a QCD

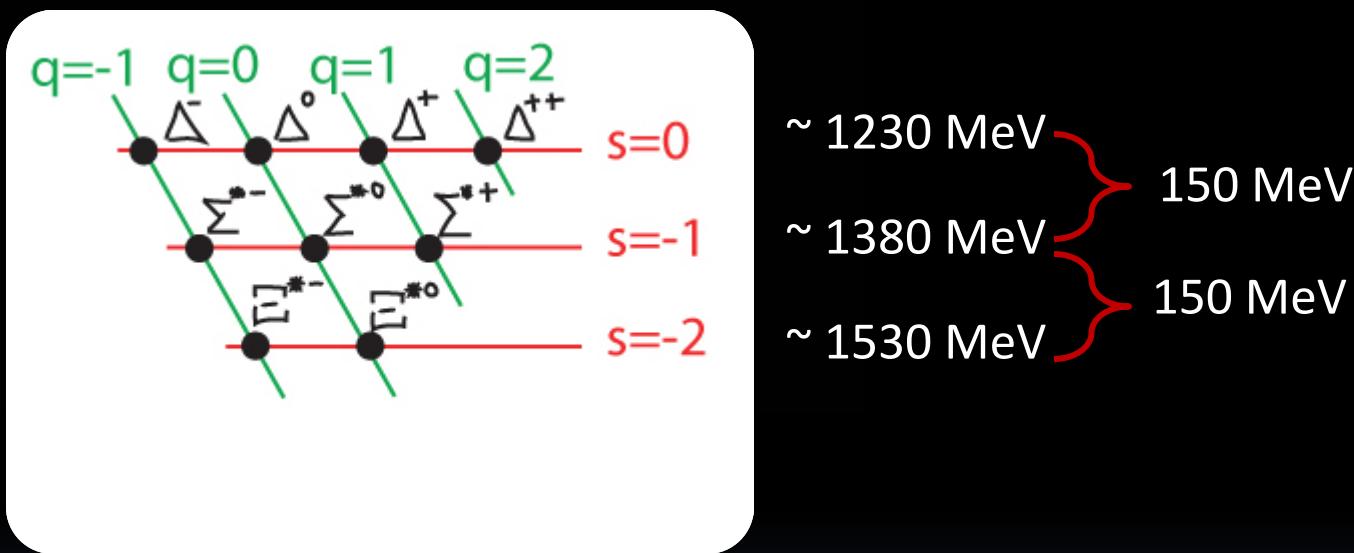
Multipletos (octeto de bárions, spin  $\frac{1}{2}$ ):

qqq	uuu	uud	udd	ddd	uus	uds	dds	uss	dss	sss
Q	+2	+1	0	-1	+1	0	-1	0	-1	-1
S	0	0	0	0	-1	-1	-1	-2	-2	-3
Bárions de spin-1/2		p	n		$\Sigma^+$	$\Sigma^0_\Lambda$	$\Sigma^-$	$\Xi^0$	$\Xi^-$	
Σlf-núcleos					V					

Proibidos por simetria!

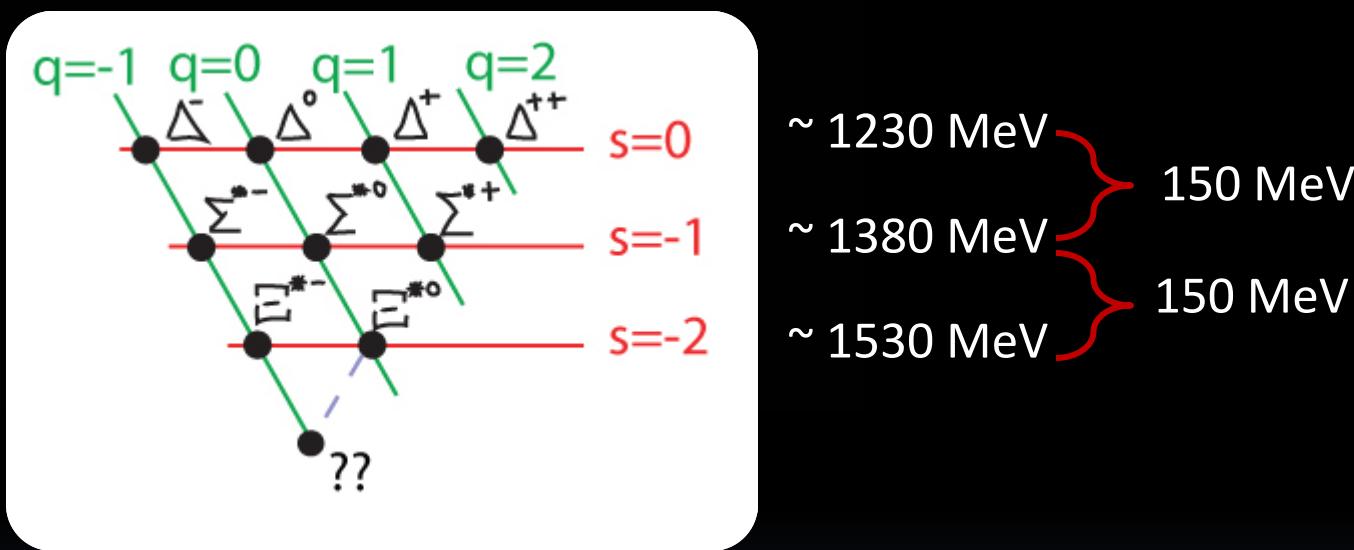
# Os Hádrons e a QCD

Multipletos (“quanto-pleto”?) de bárions, spin 3/2):

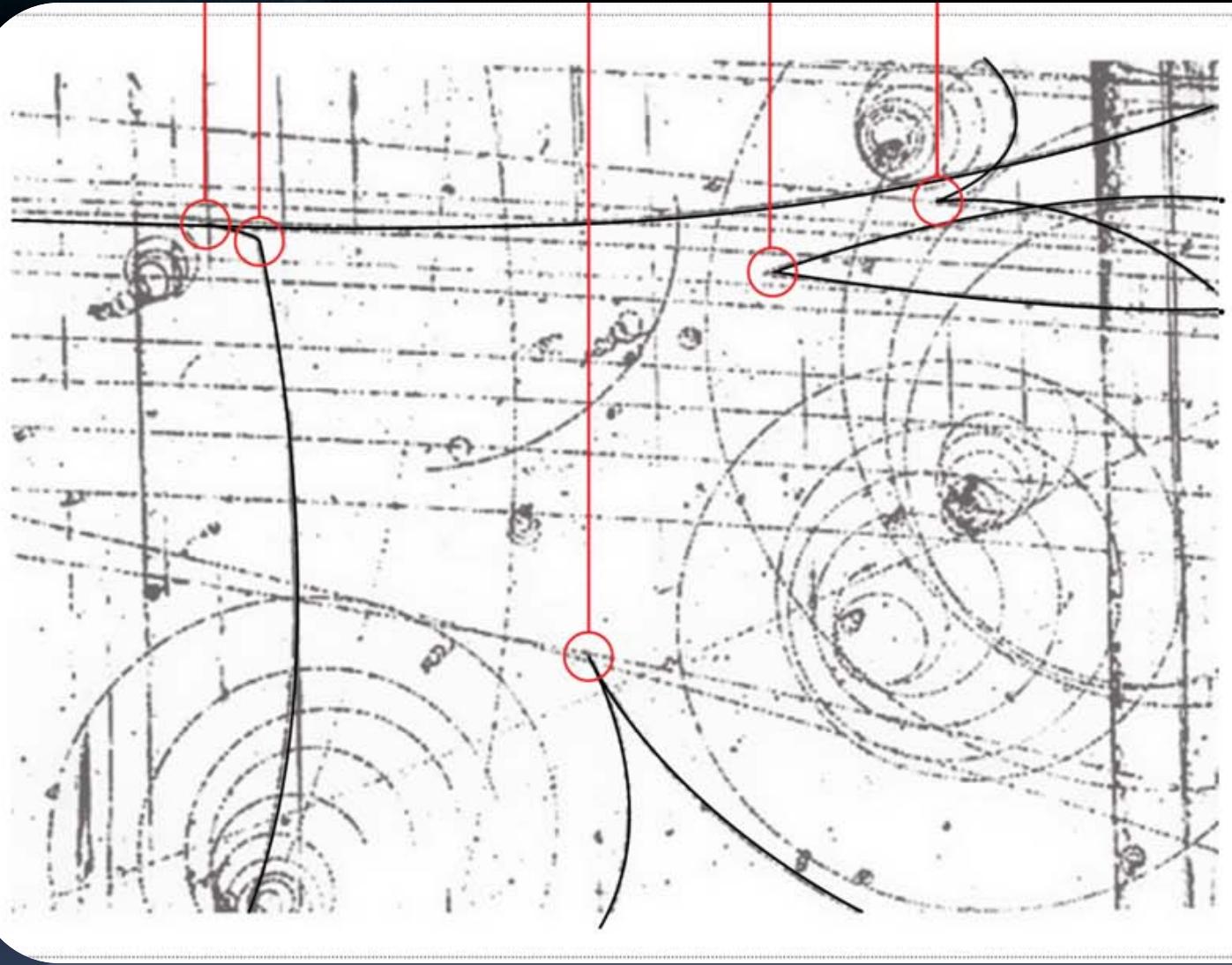


# Os Hádrons e a QCD

Multipletos (“quanto-pleto”?) de bárions, spin 3/2):



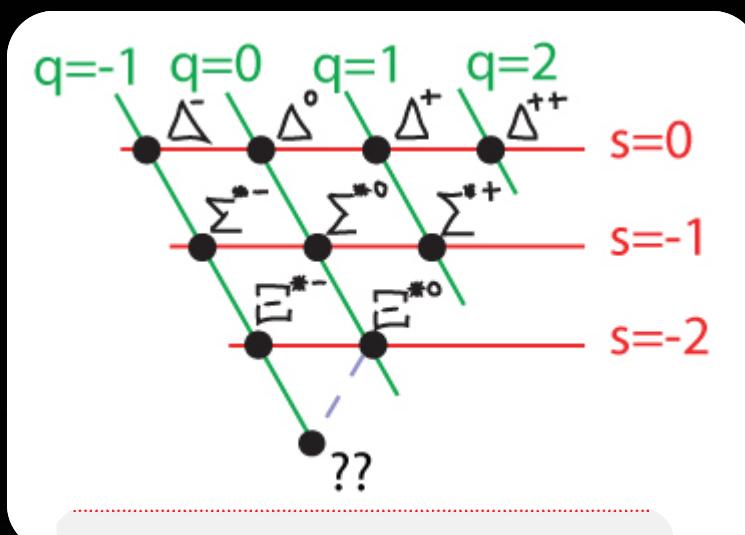
# Os Hádrons e a QCD



Exercício:  
ache o  $\Omega$

# Os Hádrons e a QCD

Multipletos (decuplo de bárions, spin 3/2):



$\Omega^-$

**OMEGA MINUS**

**massa:** 1672 MeV

spin- $\frac{3}{2}$

$Q = -1$

$S = -3$

**descoberta:** 1964

$\sim 1230$  MeV      150 MeV  
 $\sim 1380$  MeV      150 MeV  
 $\sim 1530$  MeV



Murray  
Gell-Mann

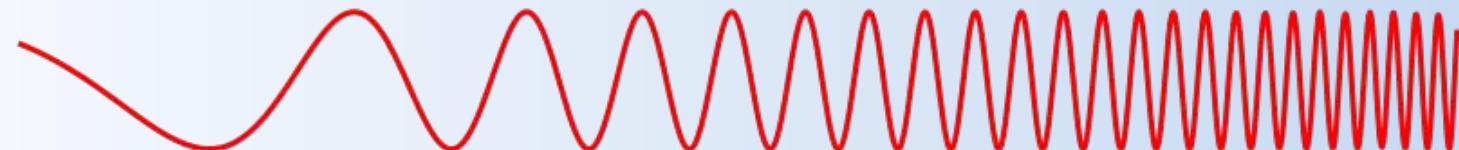
# Os Hádrons e a QCD

Multipletos (decuplo de bárions, spin 3/2):

qqq	uuu	uud	udd	ddd	uus	uds	dds	uss	dss	sss
<b>Q</b>	+2	+1	0	-1	+1	0	-1	0	-1	-1
<b>S</b>	0	0	0	0	-1	-1	-1	-2	-2	-3
Bárions de spin-3/2	$\Delta^{++}$	$\Delta^+$	$\Delta^0$	$\Delta^-$	$\Sigma^{*+}$	$\Sigma^{*0}$	$\Sigma^{*-}$	$\Xi^{*0}$	$\Xi^{*-}$	$\Omega^-$
Bárions de spin-1/2		p	n		$\Sigma^+$	$\Sigma^0$	$\Sigma^-$	$\Xi^0$	$\Xi^-$	

# Os Hádrons e a QCD

penetrates Earth's Atmosphere?



Radiation Type  
Wavelength (m)

Radio

$10^3$



Microwave

$10^{-2}$



Infrared

$10^{-5}$



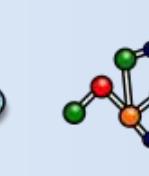
Visible

$0.5 \times 10^{-6}$



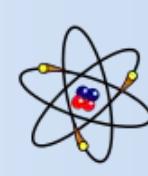
Ultraviolet

$10^{-8}$



X-ray

$10^{-10}$



Gamma ray

$10^{-12}$



Approximate Scale  
of Wavelength

Buildings

Humans

Butterflies

Needle Point Protozoans

Molecules

Atoms

Atomic Nuclei

Frequency (Hz)

$10^4$

$10^8$

$10^{12}$

$10^{15}$

$10^{16}$

$10^{18}$

$10^{20}$

Temperature of  
objects at which  
this radiation is the  
most intense  
wavelength emitted



1 K  
-272 °C

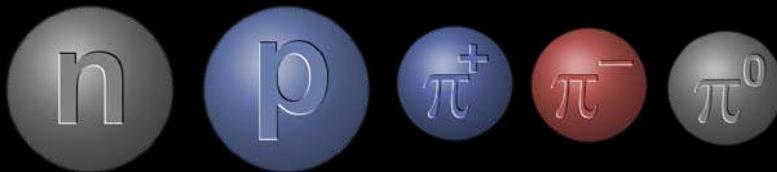
100 K  
-173 °C

10,000 K  
9,727 °C

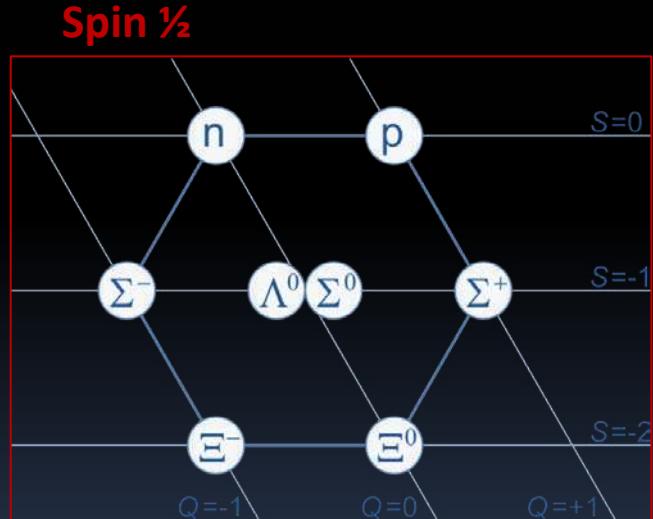
~10,000,000 K  
~10,000,000 °C

# Os Hádrons e a QCD

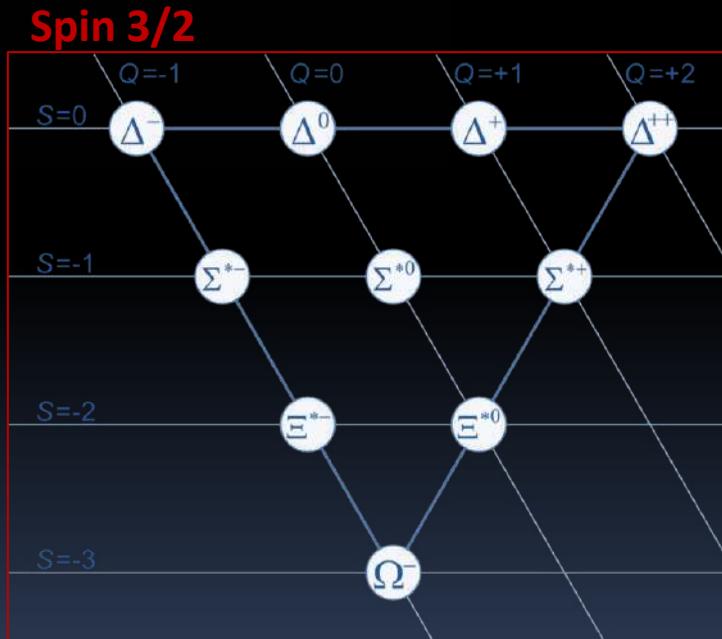
A situação era bem complicada no setor dos **hadrons**: as partículas que interagiam fortemente:



Um padrão foi lentamente emergindo:



**Estranheza S**



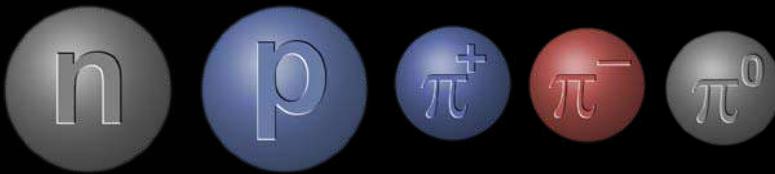
Nishijima



Gell-Mann

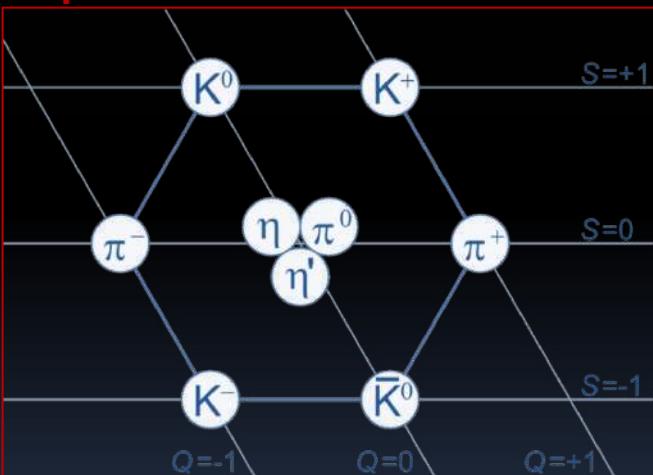
# Os Hádrons e a QCD

A situação era bem complicada no setor dos **hadrons**: as partículas que interagiam fortemente:



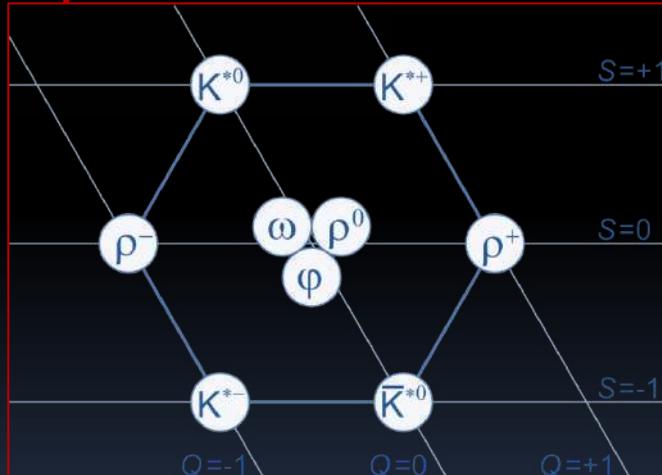
Um padrão foi lentamente emergindo:

**Spin 0**



**Estranheza S**

**Spin 1**



Nishijima



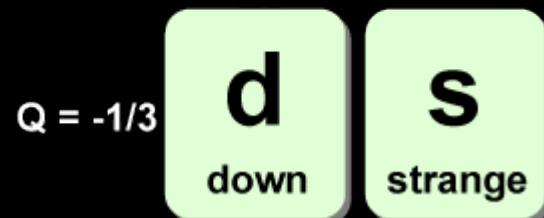
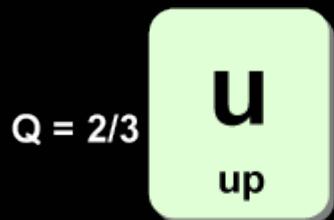
Gell-Mann

# Os Hádrons e a QCD

Zweig



"Three **quarks** for Muster Mark!"

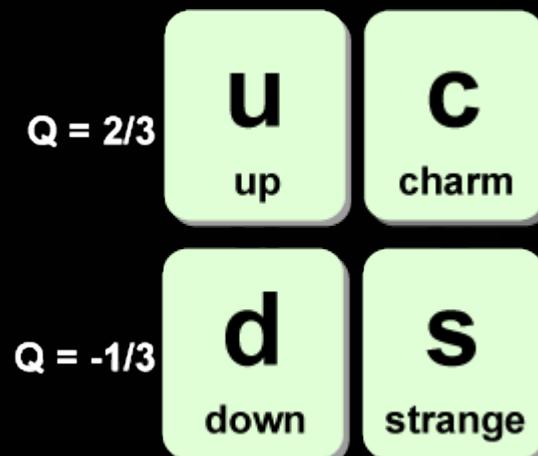


# Os Hádrons e a QCD

Zweig



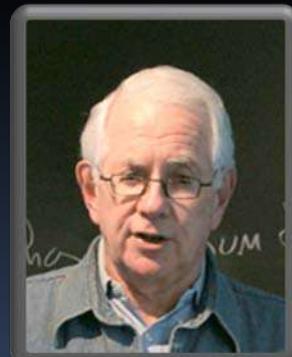
"Three quarks for Muster Mark!"



Mecanismo GIM

u,d,s,c - Sabores

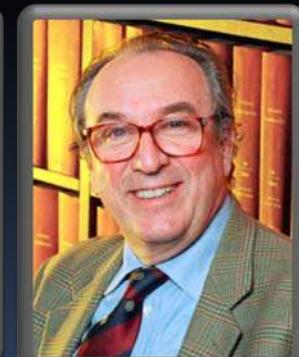
Glashow



Iliopoulos



Maiani



# Os Hádrons e a QCD

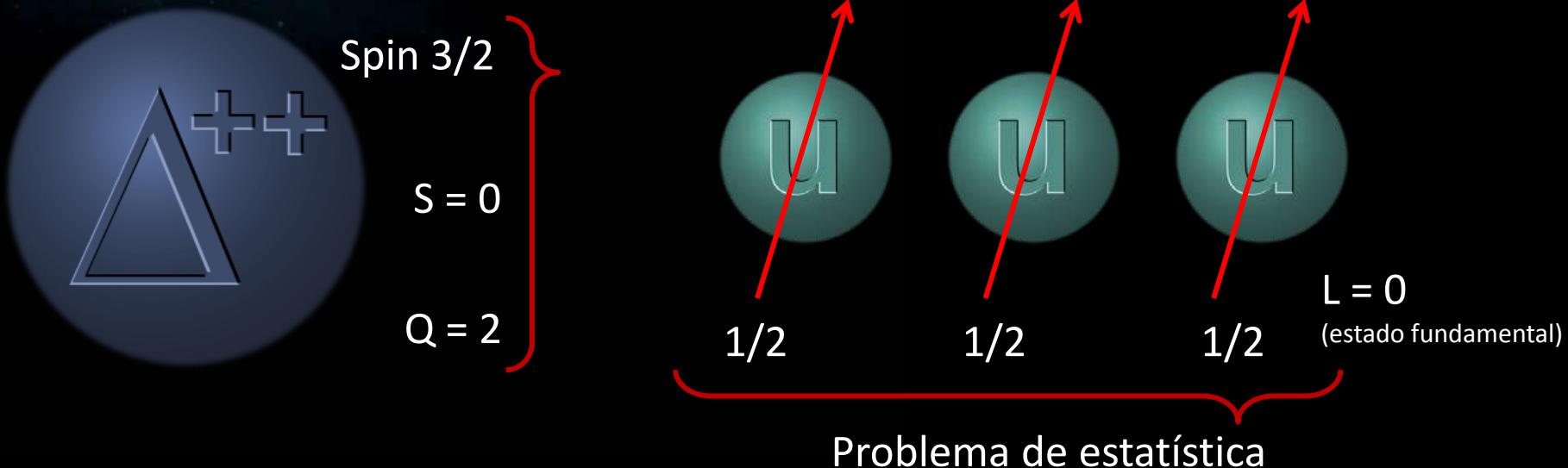


Spin 3/2

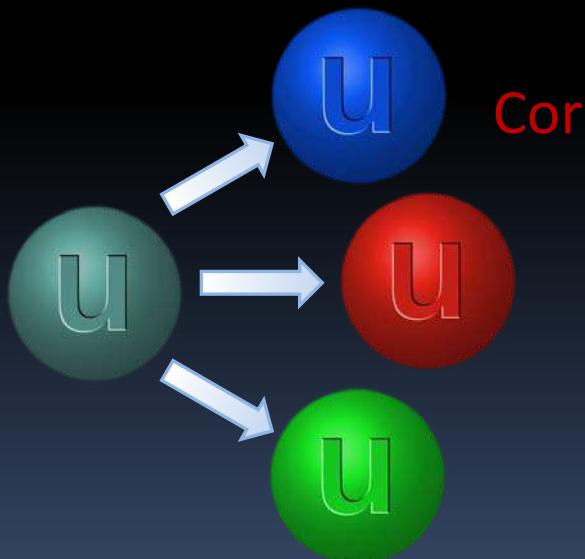
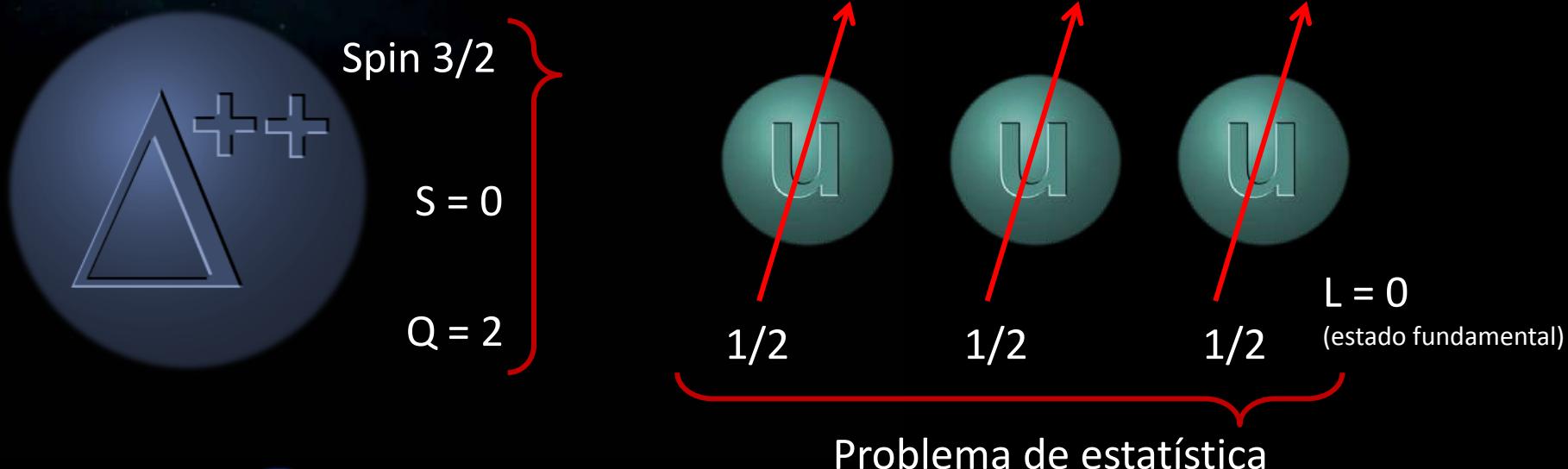
$S = 0$

$Q = 2$

# Os Hádrons e a QCD



# Os Hádrons e a QCD

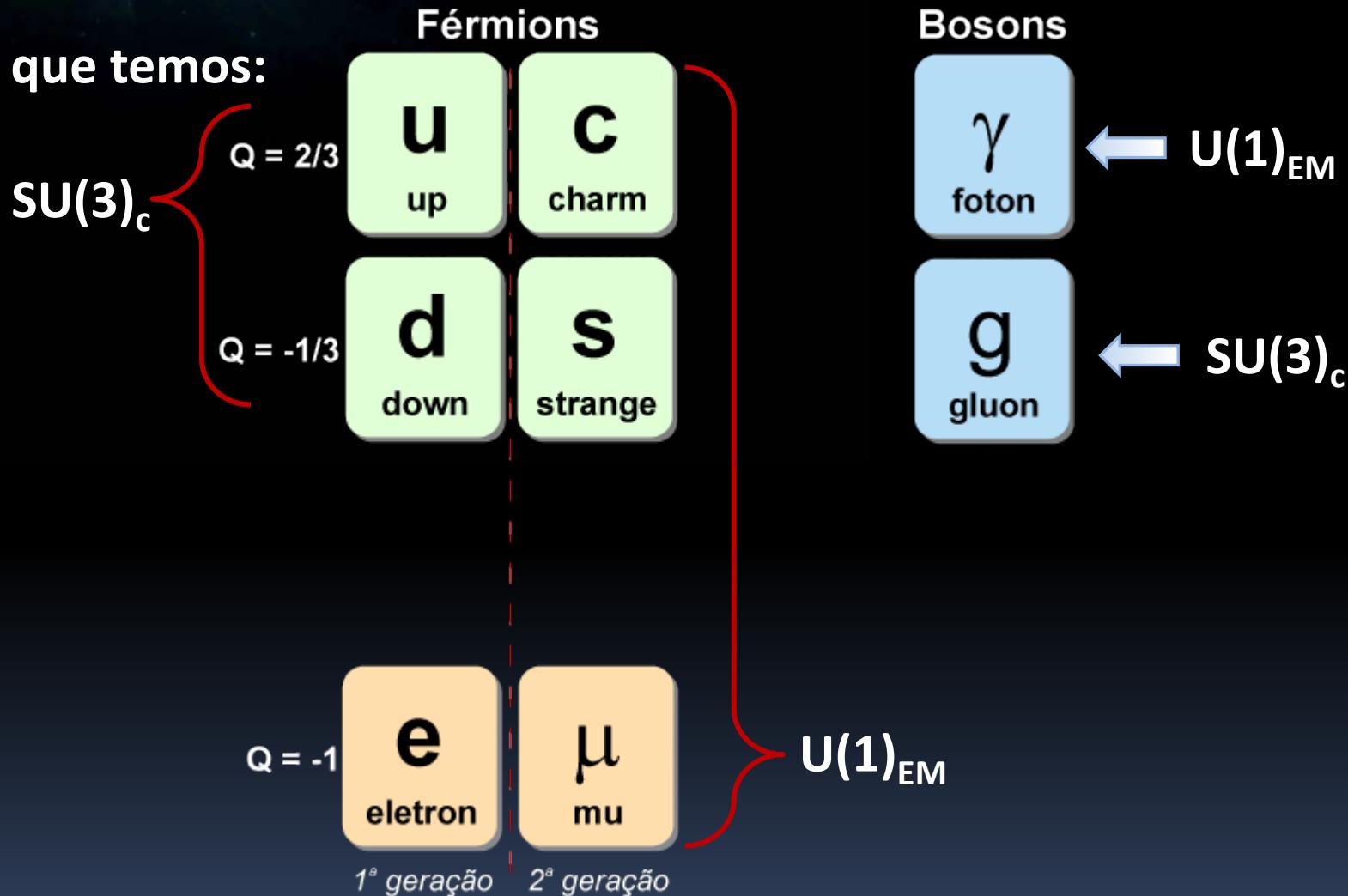


$$q = \begin{pmatrix} q_R \\ q_G \\ q_B \end{pmatrix}$$



# Construindo o Modelo Padrão da Física de Partículas

O que temos:

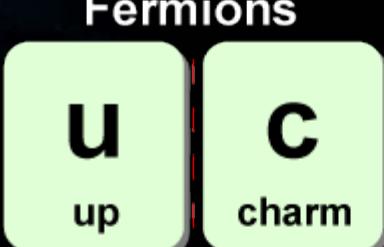


# Construindo o Modelo Padrão da Física de Partículas

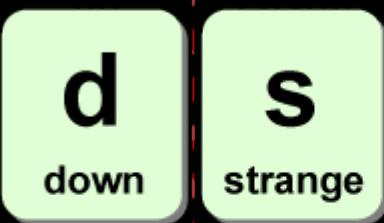
O que temos:

Quarks

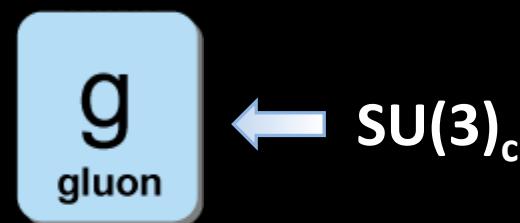
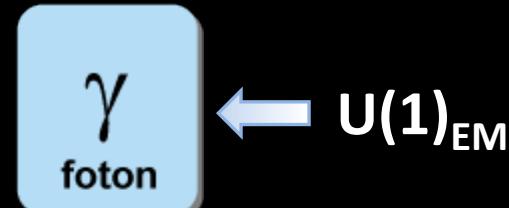
$$Q = 2/3$$



$$Q = -1/3$$



Bosons



$$Q = -1$$



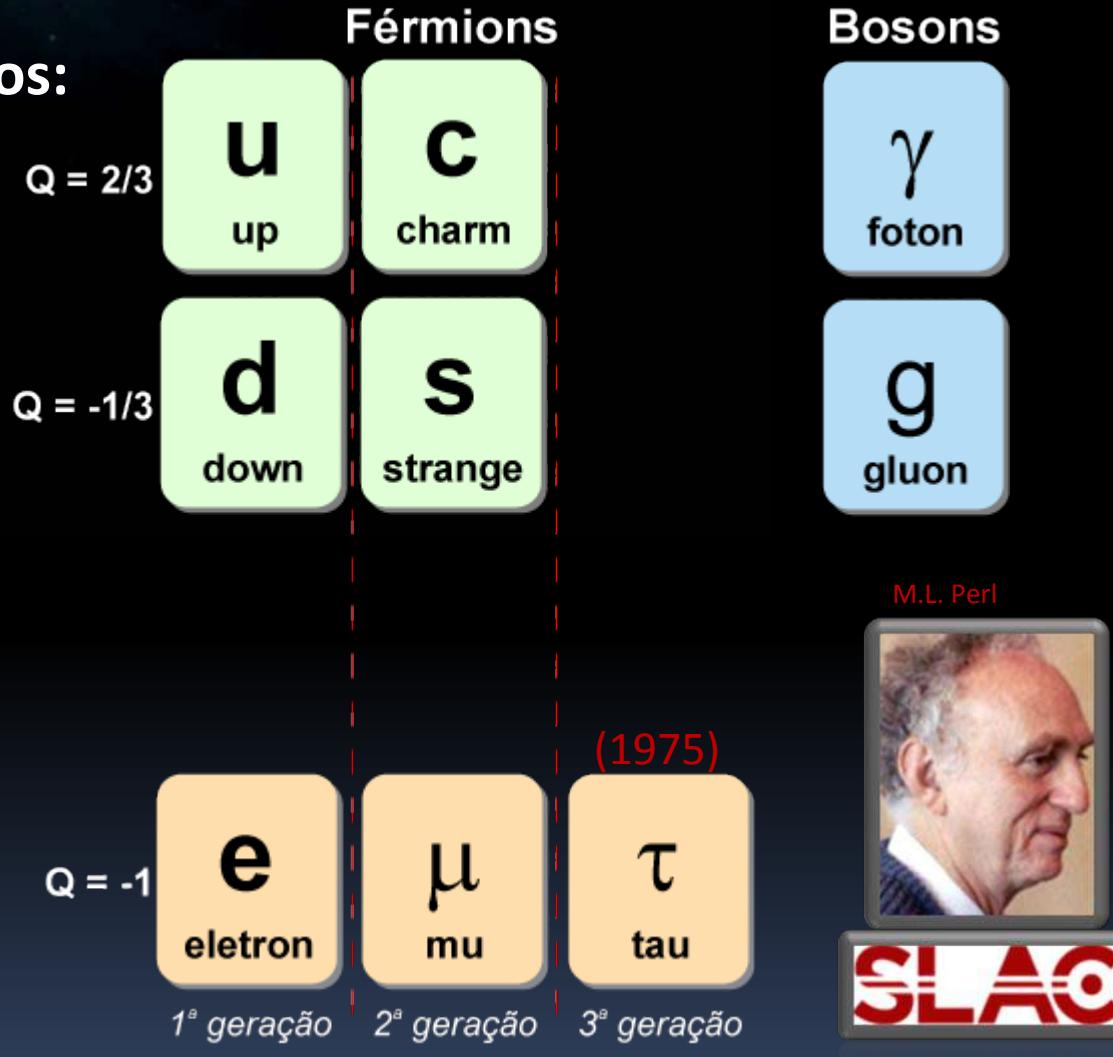
1<sup>a</sup> geração

2<sup>a</sup> geração

Leptons

# Construindo o Modelo Padrão da Física de Partículas

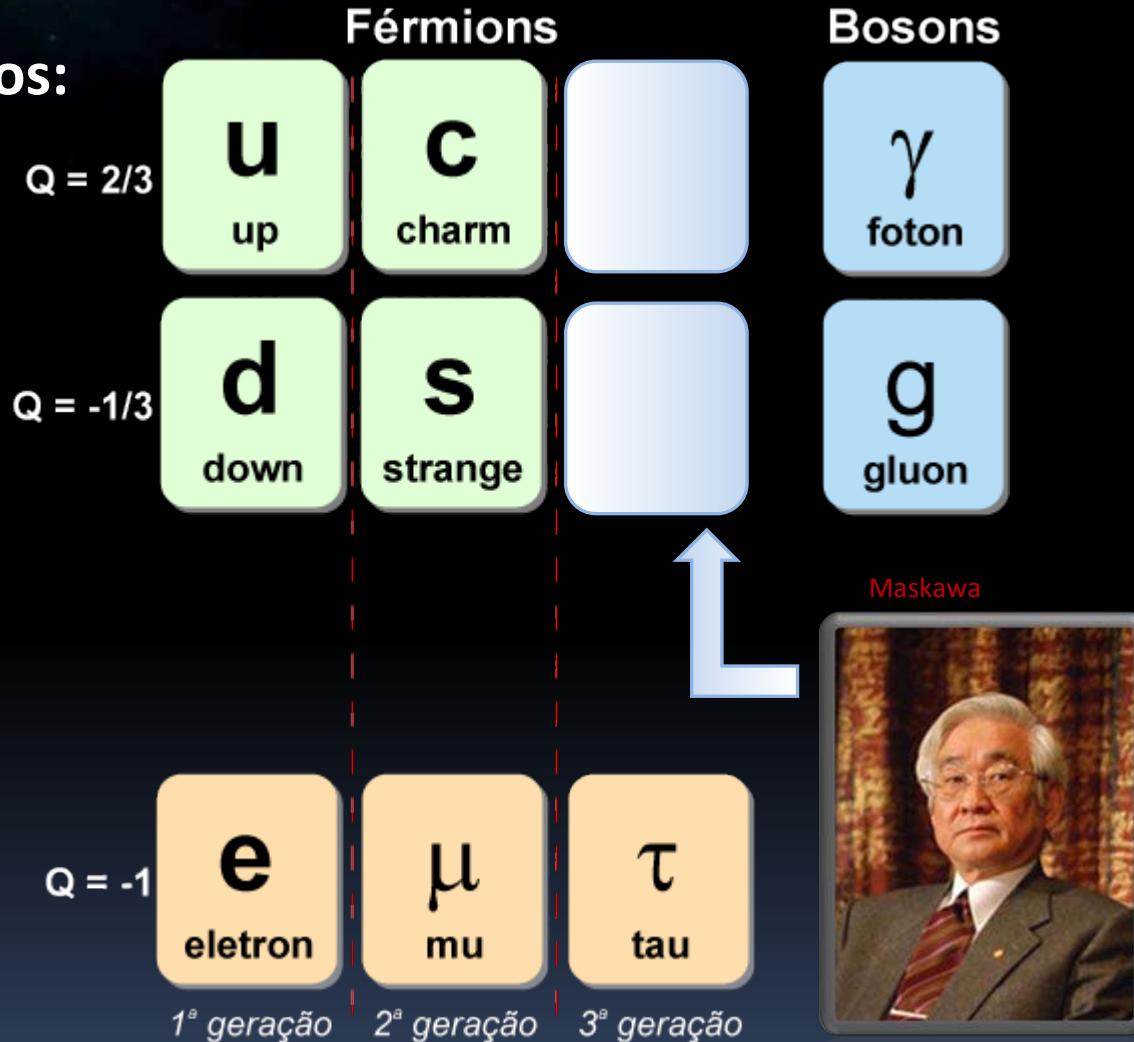
O que temos:



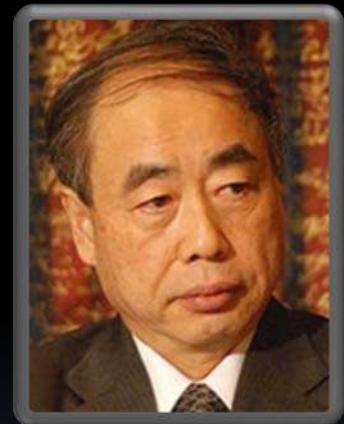
M.L. Perl

# Construindo o Modelo Padrão da Física de Partículas

O que temos:



Kobayashi



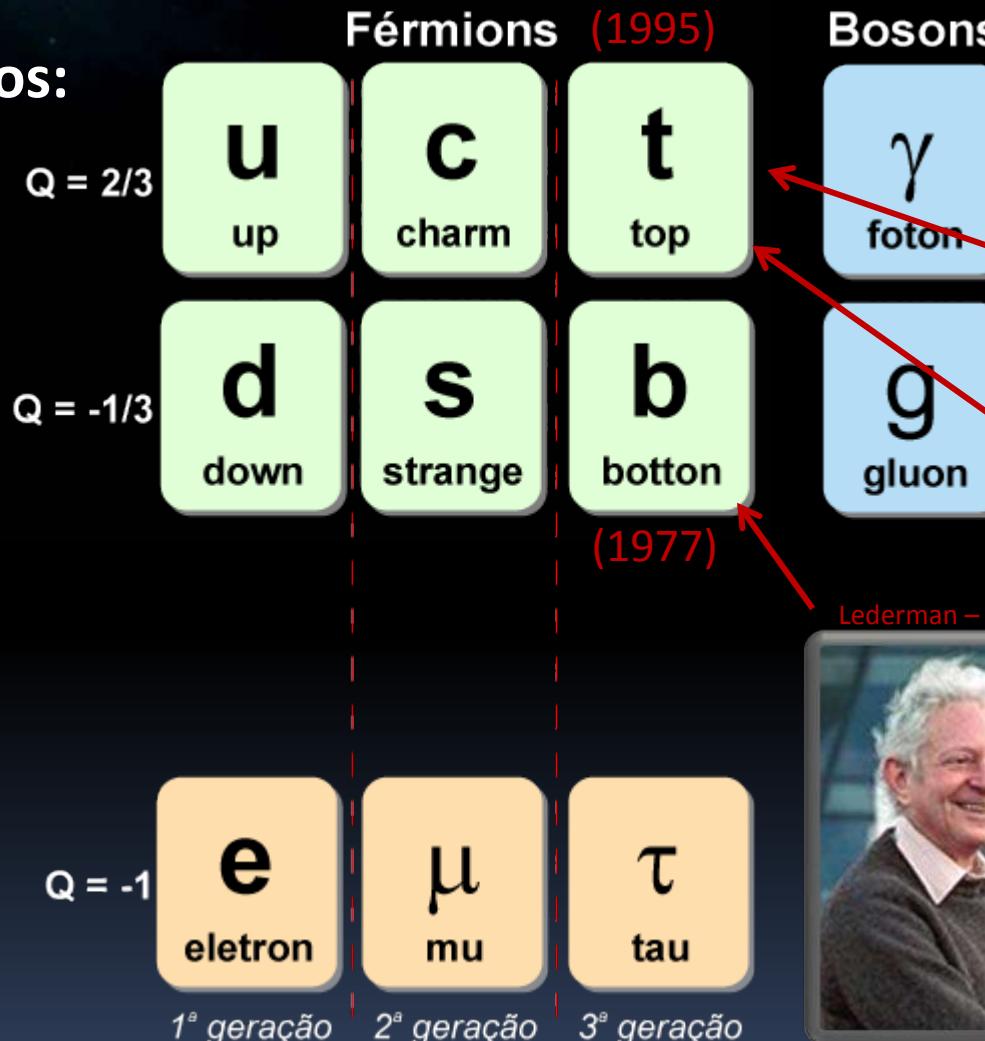
Maskawa



Violação de CP

# Construindo o Modelo Padrão da Física de Partículas

O que temos:



Lederman – E288



O (parcialmente) culpado por ouvirmos tanto "partícula de deus"

R.D.Matheus