PART XI

1) Strange pseudoscalar mesons.
Quark masses.

2) Approximate SU(3) flavor symmetry.
$S-T_3$ diagrams for pseudoscalar and vector mesons.

3) $S-T_3$ diagrams for spin 1/2 and spin 3/2 barions.
$\Delta^-, \Delta^{++}, \Omega^-$ - Problem with Pauli exclusion principle.
Color, gluons, Quantum chromodynamics.
Difference between flavor and color.

4) Heavy quarks. Charm, beauty and truth.
Mesons with hidden charm, beauty, and truth (quarkonia).
Mesons with open charm, beauty and truth.

Strange pseudoscalar mesons

meson	strangeness	quarkstructure	electric charge
K^+	1	$u\bar{s}$	$\frac{2}{3}+\frac{1}{3}=1$
K^-	-1	$\bar{u}s$	$-\frac{2}{3}-\frac{1}{3}=-1$
K^0	1	$d\bar{s}$	$-\frac{1}{3}+\frac{1}{3}=0$
$\overline{K^0}$	-1	$\bar{d}s$	$\frac{1}{3}-\frac{1}{3}=0$

Strong interaction conserves S (strangeness)

= s-quark cannot disappear in a strong process.

Isotopic structure of K-mesons

$S=1$: $\begin{pmatrix} K^+ \\ K^0 \end{pmatrix}$, $T=\frac{1}{2}$, isodoublet

$S=-1$: $\begin{pmatrix} \overline{K^0} \\ -K^- \end{pmatrix}$, $T=\frac{1}{2}$, isodoublet.

mass. $m_K \approx 500\,MeV$.

So K-mesons are much heavier than π-mesons. This is related to s-quark mass

quark masses:

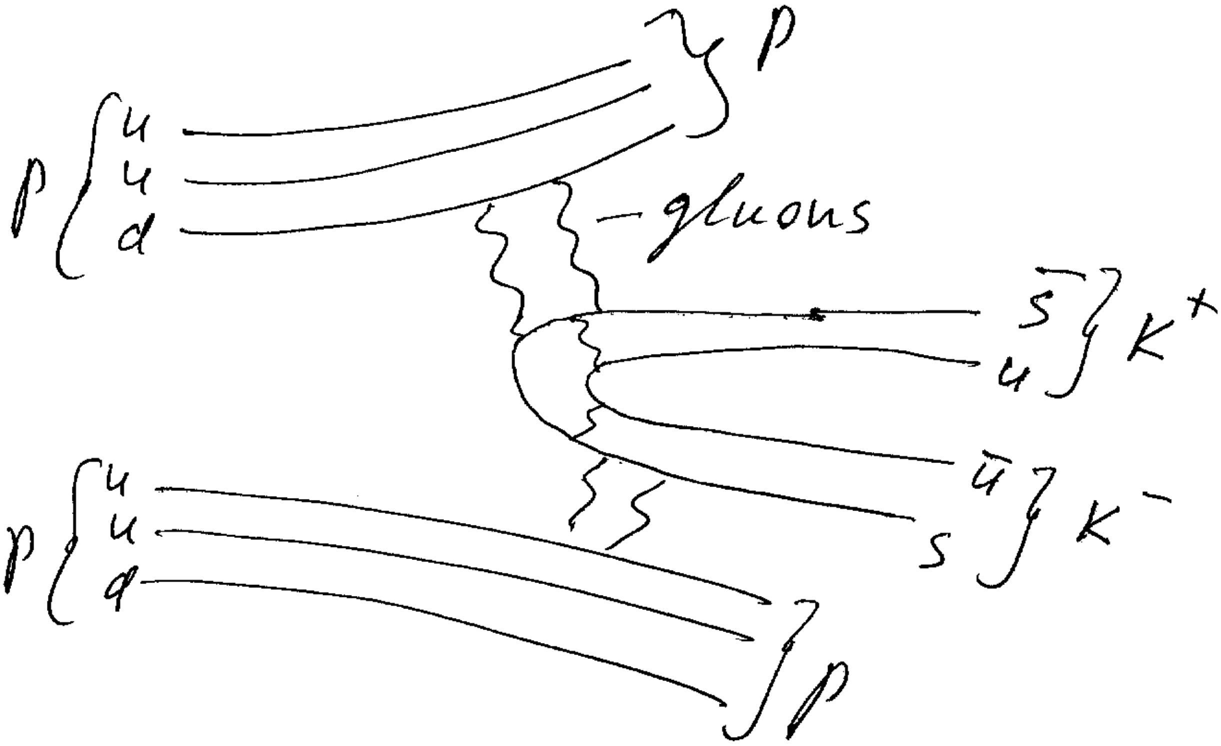
$$\left.\begin{aligned} m_u &= 1.5 \text{ to } 4.5\ MeV \\ m_d &= 5 \text{ to } 8.5\ MeV \\ m_s &= 80 \text{ to } 155\ MeV \end{aligned}\right\} \text{light quarks}$$

$$\left.\begin{aligned} m_c &= 1 \text{ to } 1.4\ GeV \\ m_b &= 4 \text{ to } 4.5\ GeV \\ m_t &= 174 \pm 5\ GeV \end{aligned}\right\} \text{heavy quarks}$$

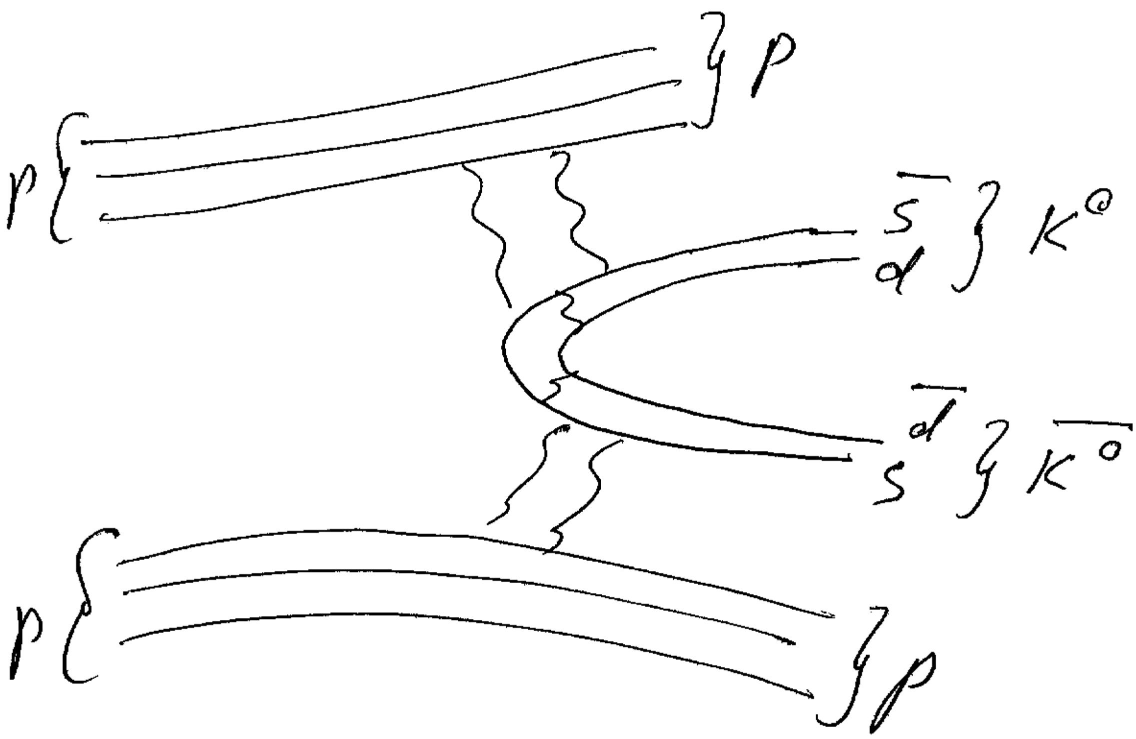
Production of K-mesons

1) Associated production in pp collisions

$pp \to pp + K^+K^-$



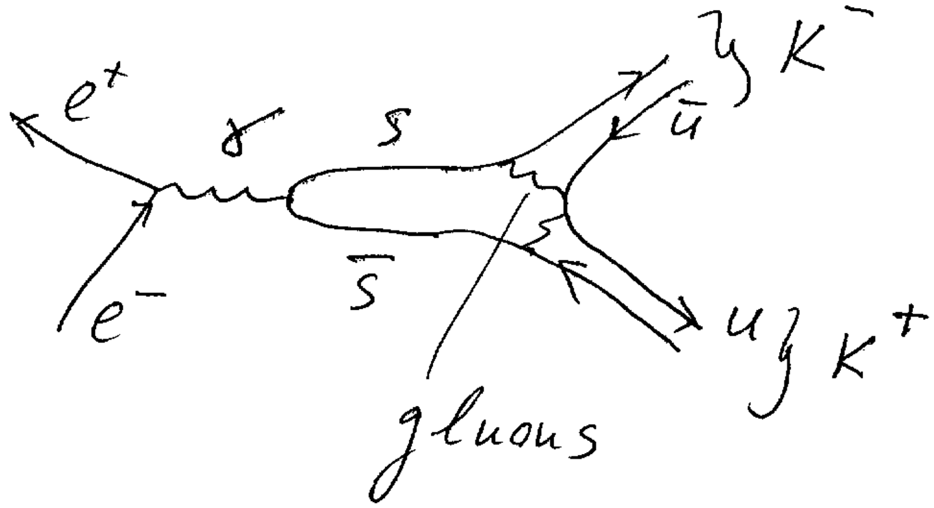
$pp \to pp K^0 \overline{K^0}$



2) electron-positron colliding beams

$e^+e^- \to K^+K^-$

$e^+e^- \to K^0\overline{K^0}$



Decays of K-mesons.

K-mesons are the lightest strange mesons. Therefore decays are possible only due to weak interaction which violates conservation of S.

lifetime $\tau_{K^\pm} = 1.24\ 10^{-8}$ sec

$\tau_{K^0} = 0.89\ 10^{-10}$ sec $\boxed{(K_S)}$

$K^+ \to \mu^+ \nu_\mu$ 63% of decays.

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$K^+ \to \pi^+ \pi^0$ 21% of decays

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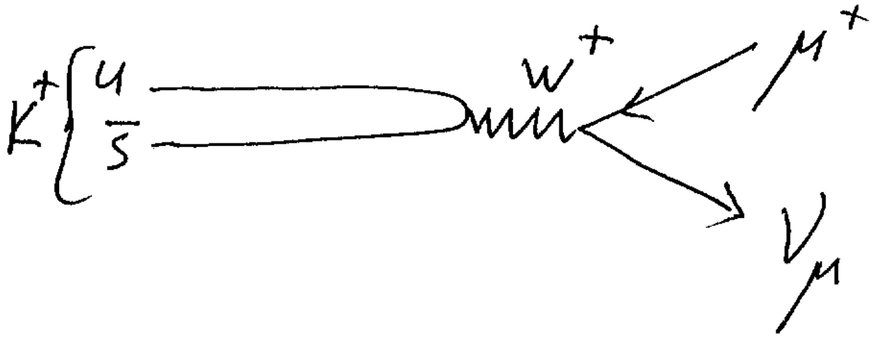
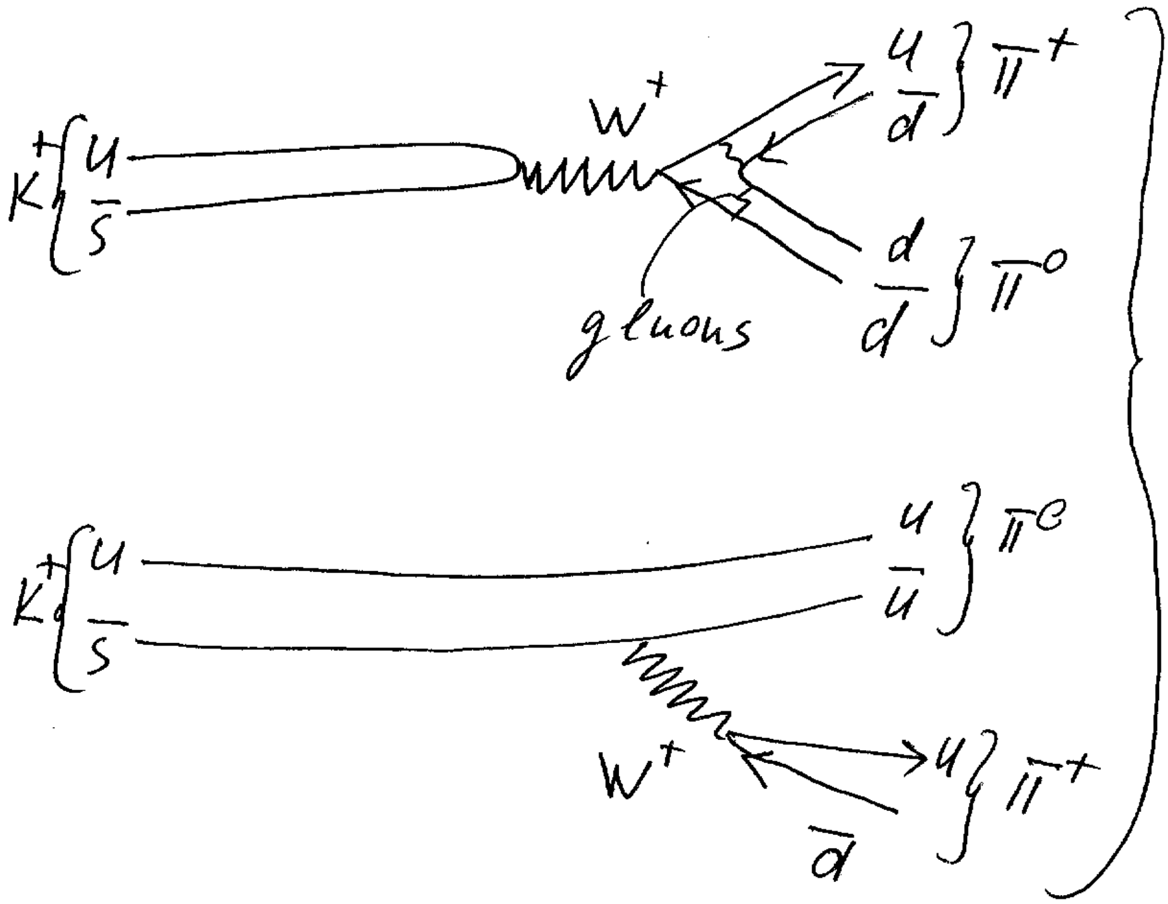


$K^+ \to \mu^+ \nu_\mu$



$K^+ \to \pi^+ \pi^0$

$K^0(K_S) \to \pi^+\pi^-$ 68.6% of decays

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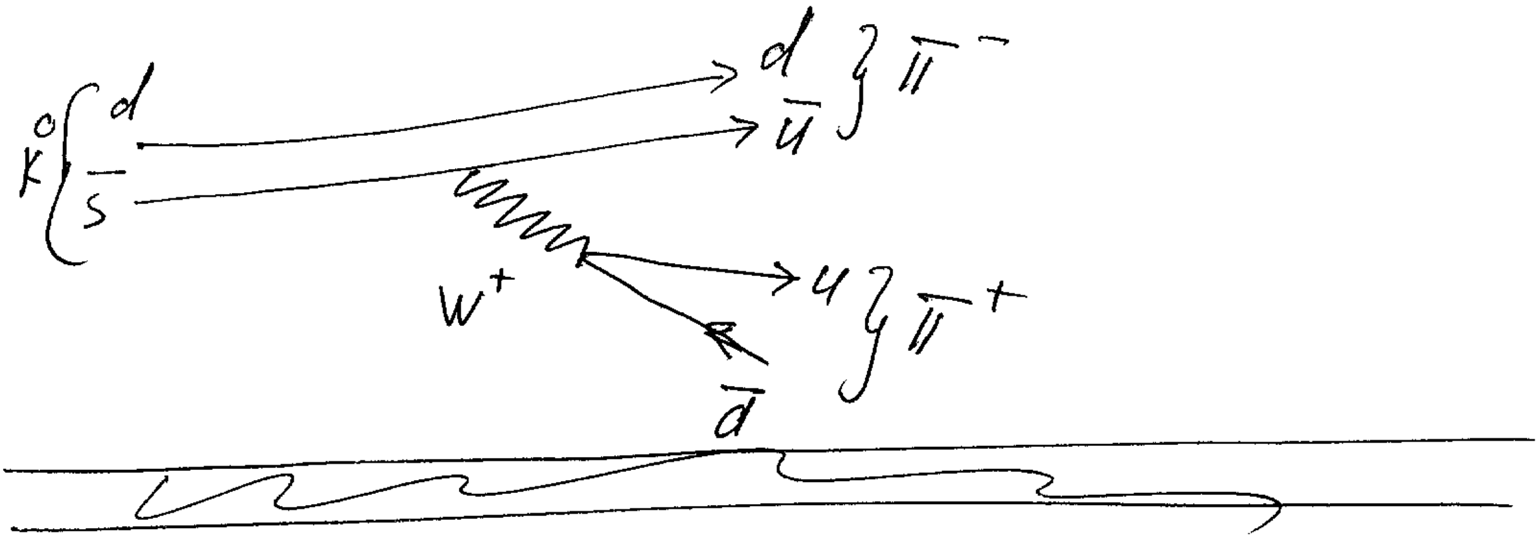


Approximate SU(3) symmetry.

$S - T_3$ diagrams for pseudoscalar and vector mesons.

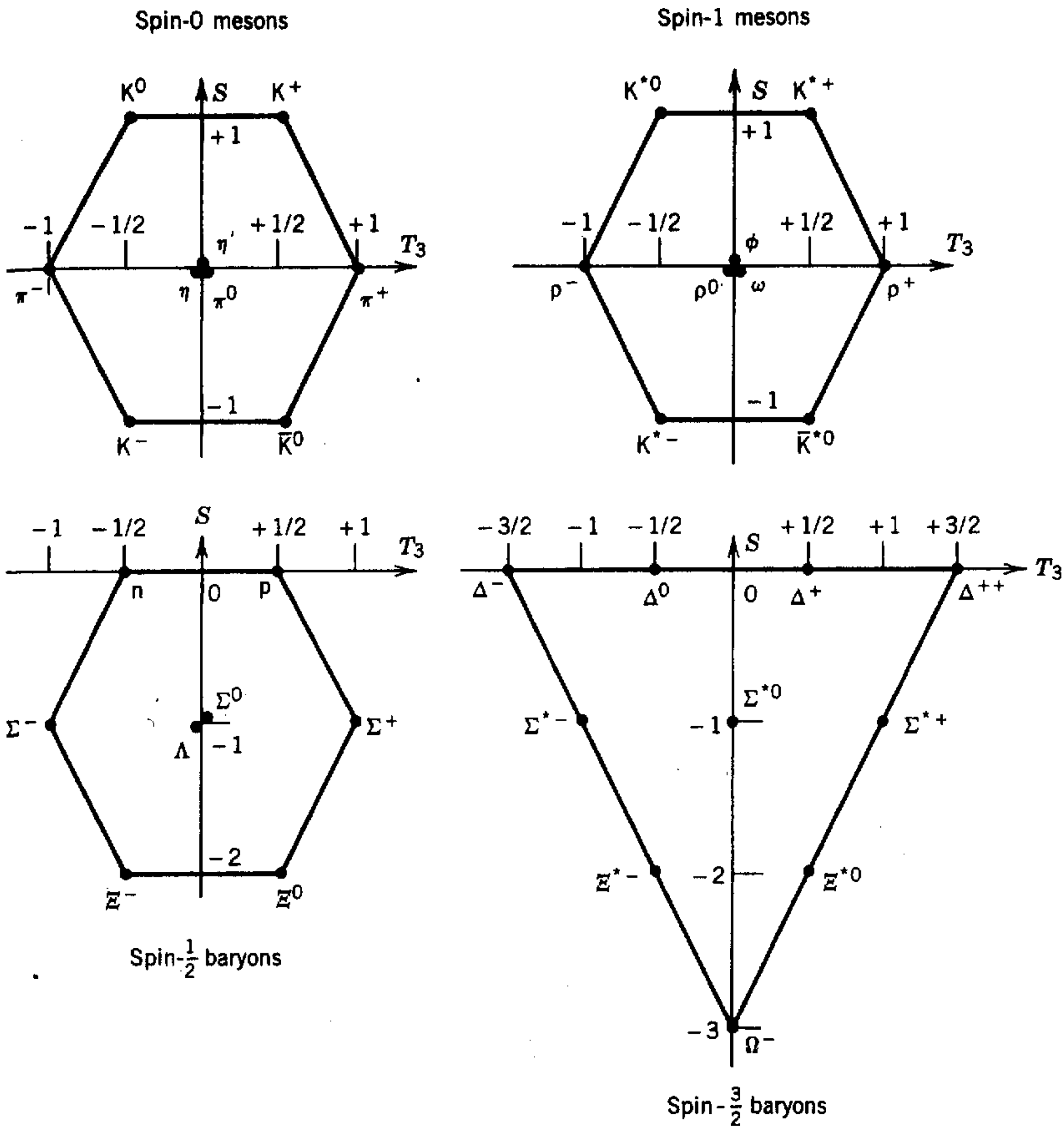


Figure 18.11 Isospin vs strangeness charts for mesons and baryons.

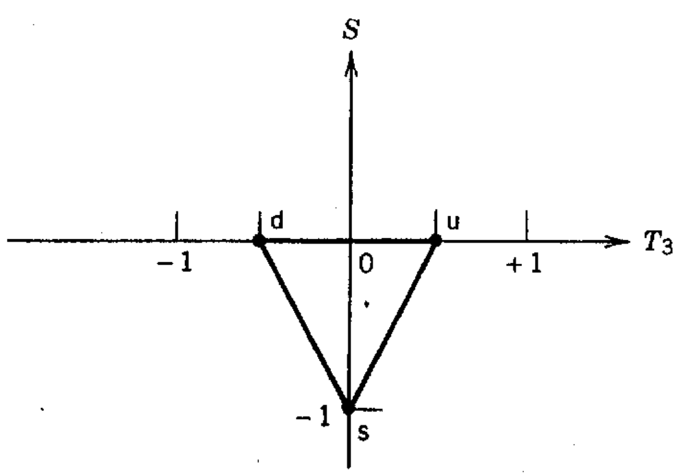


Figure 18.12 The basic three-quark triplet.

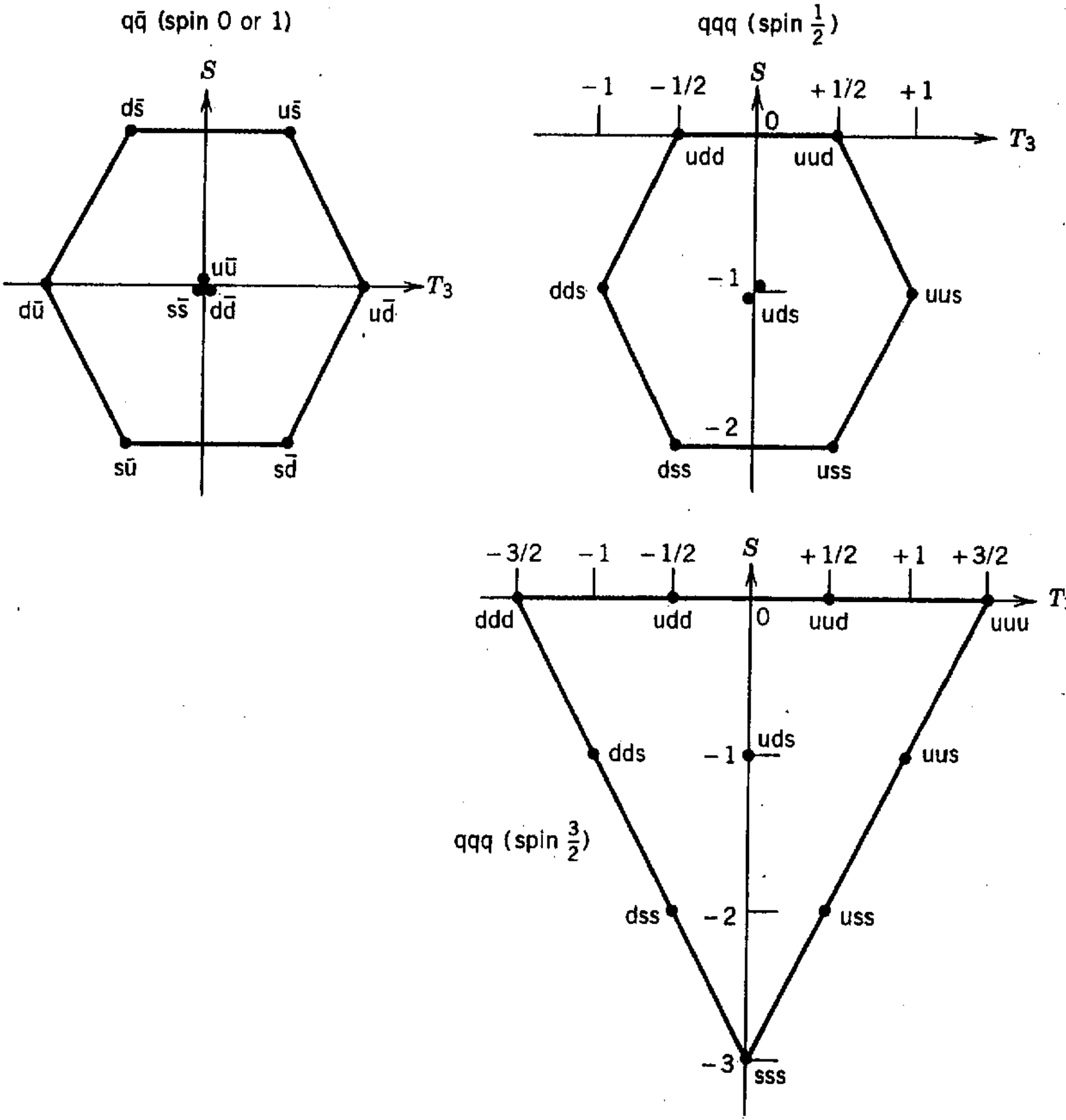


Figure 18.13 Quark-antiquark and three-quark couplings.

Octet of $s = 1/2$ barions

$m_n \approx m_p \approx 940\,MeV$

$m_\Lambda \approx 1116\ MeV$ — Λ-giperon

$m_\Sigma \approx 1190\ MeV$ — Σ-giperon

$m_\Xi \approx 1320\ MeV$ — Ξ-giperon

$$\left\{\begin{array}{l} \Sigma^+ = uus \\ \Sigma^0 = \frac{1}{\sqrt{2}}(ud+du)s \\ \Sigma^- = dds \end{array}\right. \quad \text{— isovector}$$

$$\Lambda = \frac{1}{\sqrt{2}}(ud-du)s \quad \text{— isoscalar}$$

$$\left\{\begin{array}{l} \Xi^0 = uss \\ \Xi^- = dss \end{array}\right. \quad \text{— isospinor}$$

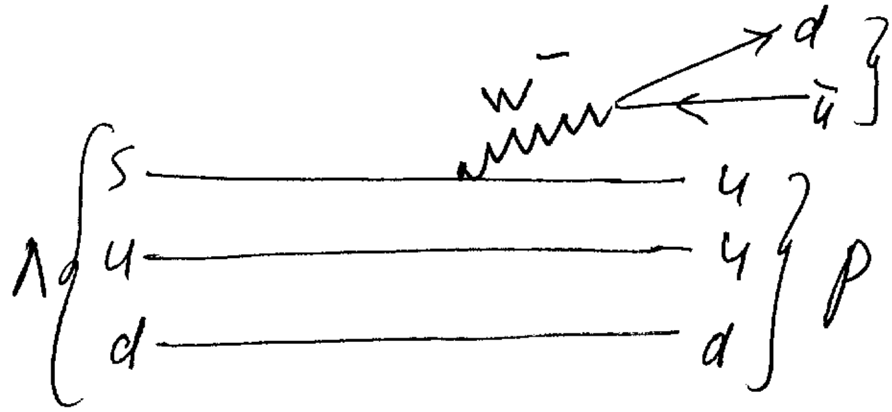
Λ-giperon, $\tau_\Lambda = 2.6\, 10^{-10}\, sec$

decay modes:

$\Lambda \to p\pi^-$ 64%

$\Lambda \to p\pi^0$ 36%

- - - - - - very small.



Λ-decay mechanism

Decuplet of $S = 3/2$ barions

		isotop spin
Δ-isobar	$m_\Delta \approx 1230\,MeV$,	$T = 3/2$
Σ^*	$m_{\Sigma^*} \approx 1385\,MeV$,	$T = 1$
Ξ^*	$m_{\Xi^*} \approx 1530\,MeV$,	$T = 1/2$
Ω^--giperon	$m_\Omega \approx 1672\,MeV$,	$T = 0$

$\Delta^- = d_\uparrow d_\uparrow d_\uparrow$

$\Delta^{++} = u_\uparrow u_\uparrow u_\uparrow$

$\Omega^- = s_\uparrow s_\uparrow s_\uparrow$

} This contradicts to the Pauli exclusion principle.

To resolve the contradiction one has to introduce an additional internal quantum number called color.

There are 3 basic colors: a, b, c

Thus

$$\begin{cases} \Delta^- = d_\uparrow^a d_\uparrow^b d_\uparrow^c \\ \Delta^{++} = u_\uparrow^a u_\uparrow^b u_\uparrow^c \\ \Omega^- = s_\uparrow^a s_\uparrow^b s_\uparrow^c \end{cases}$$

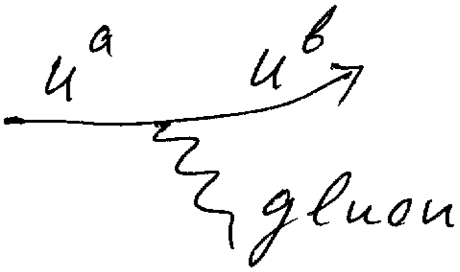
u, d, s, c, b, t – 6 flavors

a, b, c – 3 colors

Confinement of color: physical objects are "white" = "abc"

Quantum chromodynamics =
= gluodynamics.

Gluons interact with color, they do not influence the flavor



8-gluons.

Hence a gluon is a colored object. Therefor gluons are also confined.

Experimentally radius of confinement is about $1/3 - 1/2$ fm.

Heavy quarks

c – charm $\quad m_c = 1.2 \pm 0.2$ GeV

b – "beauty" $\quad m_b = 4.25 \pm 0.25$ GeV

t – "truth" $\quad m_t = 174 \pm 5$ GeV.

3 generation of quarks

$$\begin{pmatrix} u \\ d \end{pmatrix}, \begin{pmatrix} c \\ s \end{pmatrix}, \begin{pmatrix} t \\ b \end{pmatrix}$$

3 generation of leptons

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}, \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}, \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

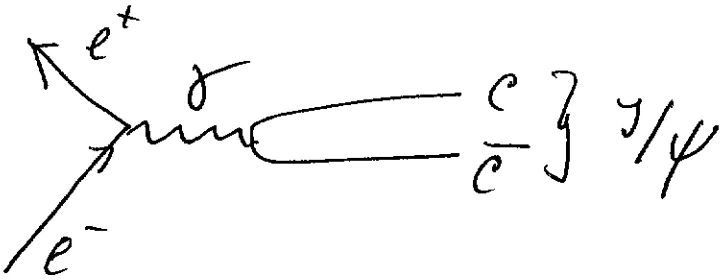
Mesons with hidden charm and beauty

$J/\psi = c\bar{c}$, $\quad J^P = 1^-$ – vecter meson

There are many radial and angular excitations of the system

$m_{J/\psi} = 3.096$ GeV

Production: $e^+e^- \to J/\psi$



Decays: $J/\psi \to e^+e^-$ 5.9%

$J/\psi \to \mu^+\mu^-$ 5.9%

$J/\psi \to \rho\pi$ 1.3%

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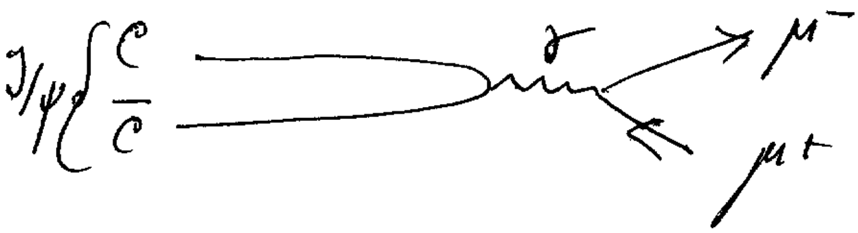
mechanism of the decay

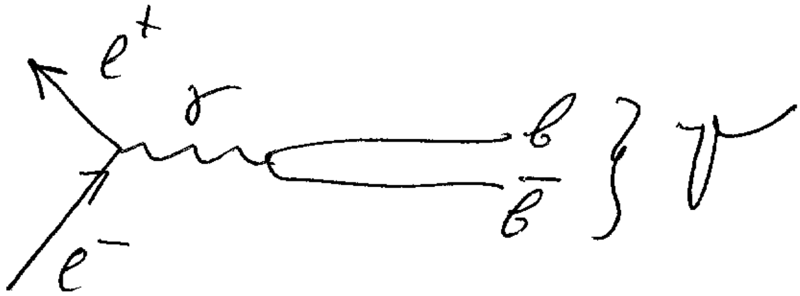


Hidden beauty

$\Upsilon = b\bar{b}$, $J^P = 1^-$ (vector meson), $m_\Upsilon = 9.46\, GeV$

There are also many angular and radial excitations of $b\bar{b}$-system.

Production: $e^+e^- \to \Upsilon$



Pseudoscalar mesons with open charm

$D^\pm$ $J^P = 0^-$, $M_{D^\pm} \simeq 1870\, MeV$

$D^+ = c\bar{d}$
$D^- = \bar{c}d$

D^0, $J^P = 0^-$, $m_{D^0} \simeq 1865$ MeV

$D^0 = c\bar{u}$

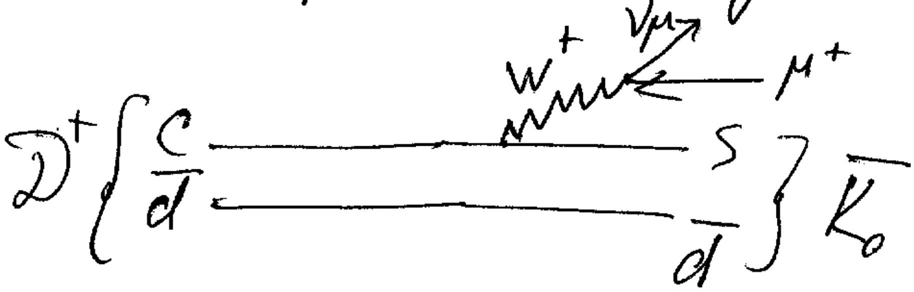
$\overline{D^0} = \bar{c}u$

isotopic structure:

$\begin{pmatrix} \overline{D^0} \\ D^- \end{pmatrix}$, $T = 1/2$, isodublet

$\begin{pmatrix} D^+ \\ -D^0 \end{pmatrix}$, $T = 1/2$, isodublet.

one of the decay modes: $D^+ \to \bar{K}^0 \mu^+ \nu_\mu$



Similarly one can constract D^* – charmed vector mesons. $J^P = 1^-$

$D^{*\pm}$, D^{*0}, $\overline{D^{*0}}$

Pseudoscalar mesons with open beauty, $J^P = 0^-$

$B^+ = \bar{b}u$

$B^- = b\bar{u}$

$m_B \approx 5.279\,GeV$

$B^0 = \bar{b}d$

$\bar{B}^0 = b\bar{d}$

Vector mesons with open beauty

$J^P = 1^-$

B^{*+}

B^{*-}

$m_{B^*} \approx 5.3\ GeV$

B^{*0}

$\bar{B}^{*0}$