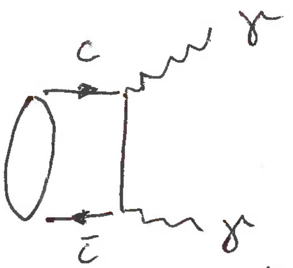
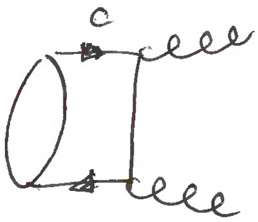
4 Decay mechanisms for quarkonia

- E/M decays
- Annihilation via virtual photon or gluon

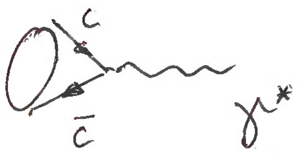
$J = 0$

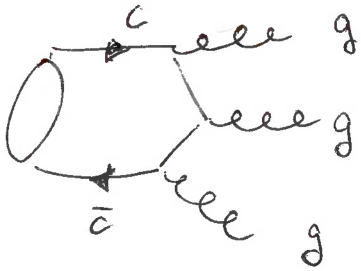




$\eta_c \to \gamma\gamma$ $\eta_c \to gg$

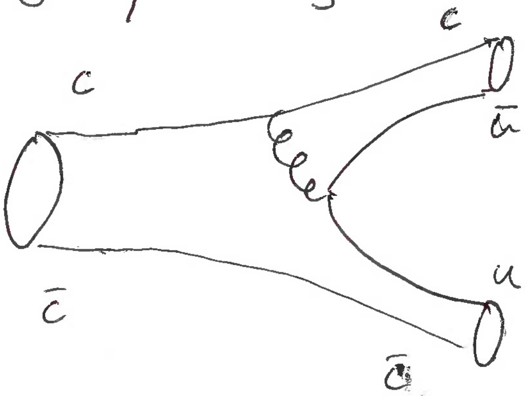
$J = 1$





$J/\psi \to \gamma^*(\to e^+e^-)$ $J/\psi \to ggg$

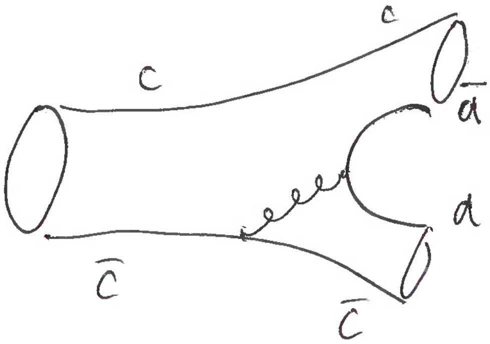
- Decay through the creation of a $q\bar{q}$ - pair



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

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

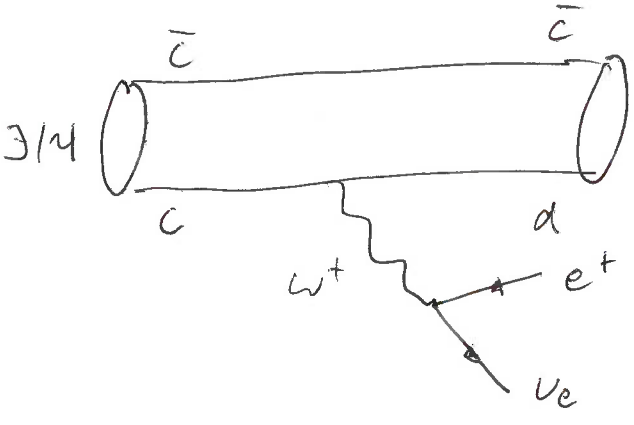
$c\bar{c} \to D^0 + \bar{D}^0$

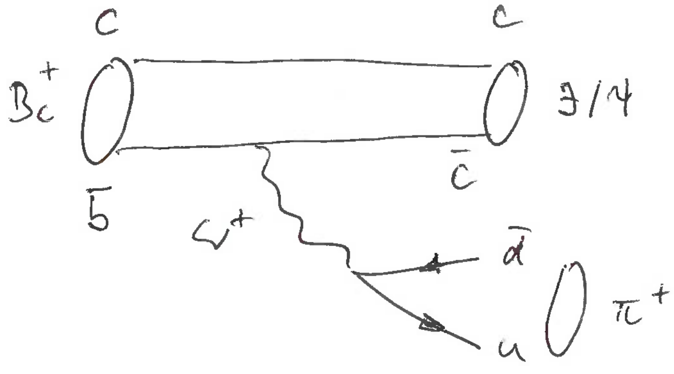


$c\bar{d} \equiv D^+$

$\bar{c}d \equiv D^-$

- Weak Decays





$J/\psi \to D^- e^+ \nu_e$ $\qquad$ $B_c^+ \to J/\psi + \pi^+$

Relative strengths of these decays?

Strong Interactions > Annihilation through γ^* > Weak Interaction

↑ Hierarchy of probabilities for the decays to occur.

Light quark mesons

Light quarks : up, down, strange

Light with respect to the binding energy of the strong force.

We can categorize mesons by their quantum numbers.

Parity for the ground state (1S states) is fixed:

$$P(q\bar{q}) = P(q)\,P(\bar{q})\,(-1)^L = -1$$

There are 2 ways the spins can align:

$\uparrow\downarrow$ $\quad J^P = 0^-$ $\quad$ pseudoscalar mesons

$\uparrow\uparrow$ $\quad J^P = 1^-$ $\quad$ vector mesons

Since there are 3 light quark, we expect a total of $3^2 = 9$ light mesons.

The strong force does not distinguish between the 3 types of light quarks.

Therefore there is an $SU(3)$ symmetry acting on the vector $\begin{pmatrix} u \\ d \\ s \end{pmatrix}$, which can be used to organise them into multiplets.

Isospin

$$\begin{pmatrix} u \\ d \end{pmatrix} \qquad I_3 = \begin{cases} +\frac{1}{2} \\ -\frac{1}{2} \end{cases} \qquad \begin{pmatrix} \uparrow \\ \downarrow \end{pmatrix}$$

Spin

$$\begin{pmatrix} -\bar{d} \\ \bar{u} \end{pmatrix} \qquad I_3 = \begin{cases} +\frac{1}{2} \\ -\frac{1}{2} \end{cases} \qquad \begin{pmatrix} \downarrow \\ \uparrow \end{pmatrix}$$

In analogy to spin, up- and down quarks and their respective antiquark can be organised in isospin vectors.

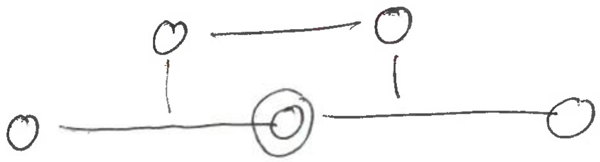
$$2 \otimes 2 = 1 \oplus 3$$

e.g. Spin $\uparrow\downarrow$ $S=0$ singlet

$\uparrow\uparrow$ — $\uparrow\downarrow$ — $\downarrow\downarrow$ $S=1$ triplet

More generally one can use weight diagrams

2 

$2 \otimes 2$  $1 \oplus 3$

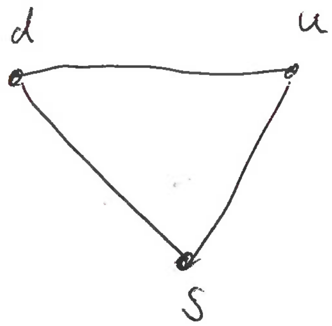
$|\bar{u} d\rangle \quad - \quad |u\bar{u}\rangle - |d\bar{d}\rangle \quad - \quad |u\bar{d}\rangle$

$|u\bar{u}\rangle + |d\bar{d}\rangle$

Meson multiplets

Generalisation to $SU(3)$ acting on the vector $\begin{pmatrix} u \\ d \\ s \end{pmatrix}$

weight diagrams



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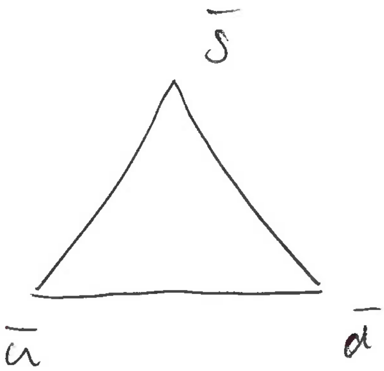
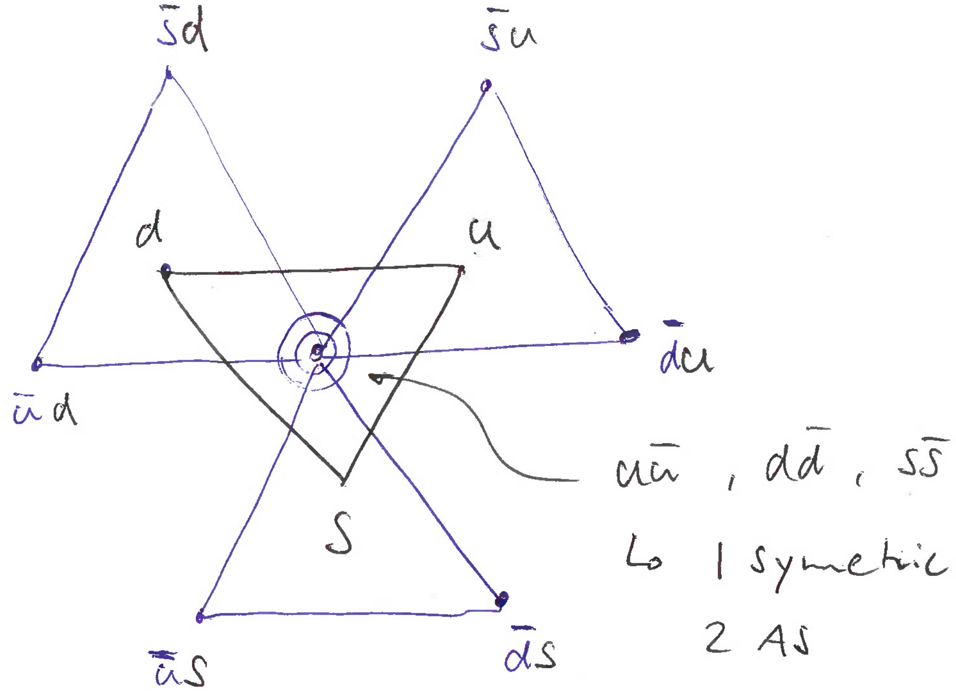


$\bar{3}$

$3 \otimes \bar{3} = 1 \oplus 8$



$\bar{s}d$
$\bar{s}u$
d
u
$\bar{u}d$
$\bar{d}u$
s
$\bar{u}s$
$\bar{d}s$
$u\bar{u}$, $d\bar{d}$, $s\bar{s}$
↳ 1 symetric
2 AS

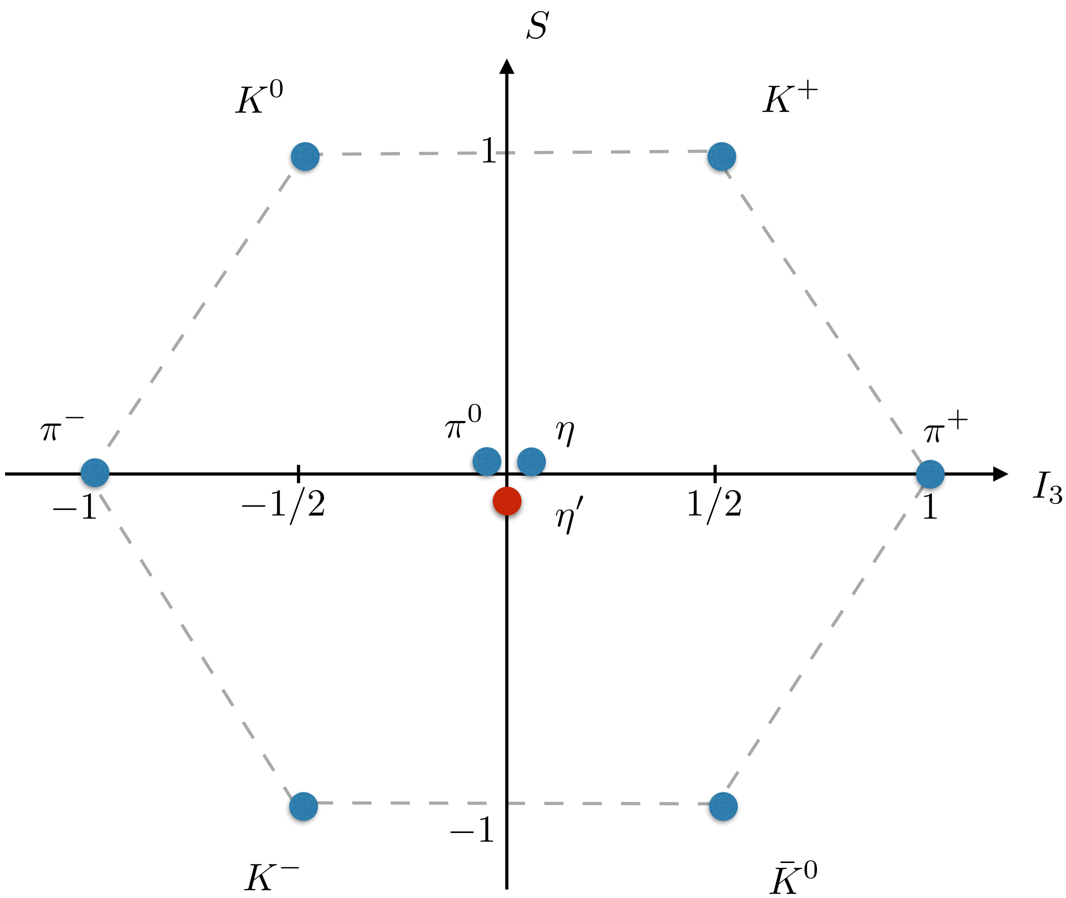


Figure 6: Pseudo-scalar mesons in the I_3/S plane.

Flavour octet:

$$
\left.\begin{array}{lcc}
|\pi^+\rangle & = & |u\bar{d}\rangle \\
|\pi^-\rangle & = & |d\bar{u}\rangle \\
|\pi^0\rangle & = & \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle - |d\bar{d}\rangle\right)
\end{array}\right\} I = 1,\ S = 0
$$

$$
\left.\begin{array}{lcl}
|K^+\rangle & = & |u\bar{s}\rangle \\
|K^0\rangle & = & |d\bar{s}\rangle
\end{array}\right\} I = 1/2,\ S = +1
$$

$$
\left.\begin{array}{lcl}
|K^-\rangle & = & |s\bar{u}\rangle \\
|\bar{K}^0\rangle & = & |s\bar{d}\rangle
\end{array}\right\} I = 1/2,\ S = -1
$$

$$
|\eta\rangle = \frac{1}{\sqrt{6}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle - 2\,|s\bar{s}\rangle\right) \Big\} \ I = 0,\ S = 0
$$

Flavour singlet:

$$
|\eta'\rangle = \frac{1}{\sqrt{3}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle + |s\bar{s}\rangle\right)
$$

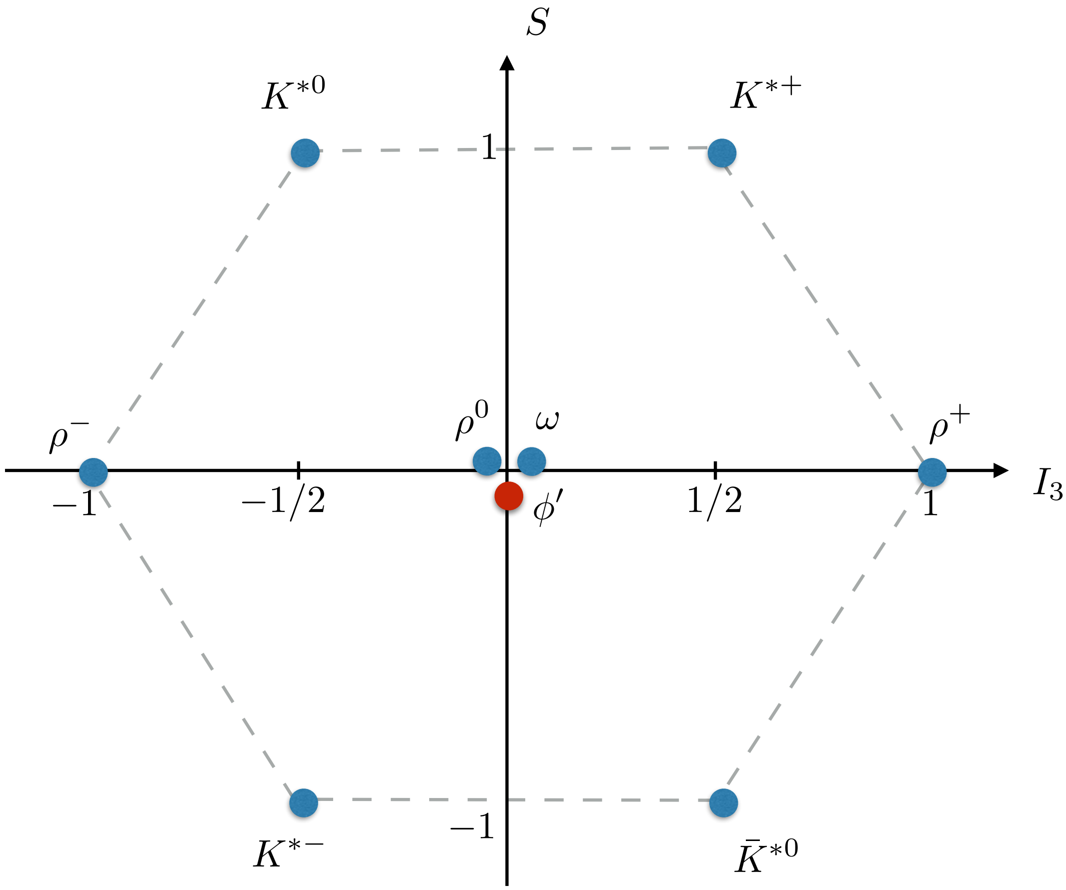


Figure 7: Vector mesons in the I_3/S plane.

Flavour octet:

$$\left.\begin{array}{lcc} |\rho^+\rangle &=& |u\bar{d}\rangle \\ |\rho^-\rangle &=& |d\bar{u}\rangle \\ |\rho^0\rangle &=& \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle - |d\bar{d}\rangle\right) \end{array}\right\} I=1,\ S=0$$

$$\left.\begin{array}{lcc} |K^{*+}\rangle &=& |u\bar{s}\rangle \\ |K^{*0}\rangle &=& |d\bar{s}\rangle \end{array}\right\} I=1/2,\ S=+1$$

$$\left.\begin{array}{lcc} |K^{*-}\rangle &=& |s\bar{u}\rangle \\ |\bar{K}^{*0}\rangle &=& |s\bar{d}\rangle \end{array}\right\} I=1/2,\ S=-1$$

Flavour octet and singlet mixture:

$$\left.\begin{array}{lcc} |\phi\rangle &=& |s\bar{s}\rangle \\ |\omega\rangle &=& \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle\right) \end{array}\right\} I=0,\ S=0$$