7. Building particles from quarks

The observed particles were either leptons, three quark groupings or quark-antiquark pairs. Three quark groupings or quark-antiquark pairs are called **hadrons**.

The **hadrons** containing three quarks (or three antiquarks) are known as **baryons** (baryon means 'heavy')

The **hadrons** containing quark-antiquark pairs are known as **mesons** (meson originally meant medium mass but it was eventually recognised that many mesons have masses greater than some baryons)

The quark content of some typical baryons and mesons is listed below. It can be seen that all of the particles can be constructed from the basic quarks and antiquarks of the quark family.

In some cases it can be see that a particle is seen as a combination of quark pairs. This way of presenting the combination reflects the mathematical descriptions of the particles.

Baryons (spin 1/2):

p = uud n = udd Λ = uds Σ^+ = uus Σ^0 = uds Σ^- = dds Ξ^0 = uss Ξ^- = dss Λ^+_c = udc

Baryons (spin 3/2)

Δ^{++} = uuu Δ^+ = uud, Δ^0 = udd Δ^- = ddd Σ^{*+} = uus Σ^{*0} = uds Σ^{*-} = dds Ξ^{*0} = uss

Ξ^{*-} = dss Ω^- = sss

Pseudoscalar mesons (spin 0)

$\pi^+ = u\bar{d}$ $\pi^- = d\bar{u}$ $\pi^0 = (u\bar{u} - d\bar{d})/\sqrt{2}$	
$K^+ = u\bar{s}$ $K^- = s\bar{u}$ $K^0 = d\bar{s}$ $\bar{K}^0 = s\bar{d}$	
$\eta = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$	$\eta' = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$
$D^+ = c\bar{d}$ $D^- = d\bar{s}$ $D^+_s = c\bar{s}$ $D^-_s = s\bar{c}$ $D^0 = c\bar{u}$ $\bar{D}^0 = u\bar{c}$	
$B^+ = u\bar{b}$ $B^- = b\bar{u}$ $B^0 = d\bar{b}$ $\bar{B}^0 = b\bar{d}$	
$\eta_c = c\bar{c}$	

Vector mesons (spin 1)

$\rho^+ = u\bar{d}$	$\rho^- = d\bar{u}$	$\rho^0 = (u\bar{u} - d\bar{d})/\sqrt{2}$	
$K^{*+} = u\bar{s}$	$K^{*-} = s\bar{u}$	$K^{*0} = d\bar{s}$	$\bar{K}^{*0} = s\bar{d}$
$\omega = (u\bar{u} + d\bar{d})/\sqrt{2}$			
$\phi = s\bar{s}$	$J/\psi = c\bar{c}$	$T = b\bar{b}$	
$K^{*+} = u\bar{s}$	$K^{*-} = s\bar{u}$	$K^{*0} = d\bar{s}$	$\bar{K}^{*0} = s\bar{d}$

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http://teachers.web.cern.ch/teachers/archiv/HST2002/feynman/index.html

9. How to construct Feynman diagrams of purely leptonic weak interactions

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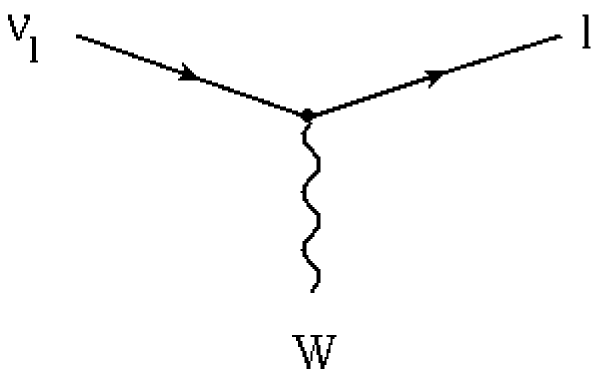
The basic vertex of purely leptonic weak interactions is shown in Fig. 1.

Fig. 1: Purely leptonic weak interactions.



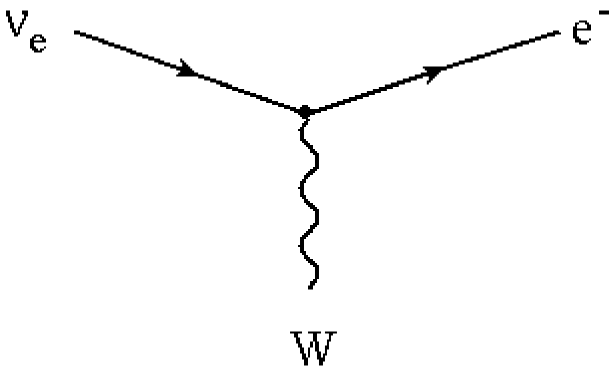
This vertex is used for all allowed interactions between all leptons. It is a prototype in which we replace the neutrino and the lepton l by the corresponding allowed neutrino-lepton pairs as shown in Fig. 2.

Fig. 2: Allowed interactions between neutrinos and leptons.

$$\begin{array}{ccc} \nu_e & \nu_\mu & \nu_\tau \\ \updownarrow & \updownarrow & \updownarrow \\ e^- & \mu^- & \tau^- \end{array}$$

Let's take as an example the weak interaction between an electron-neutrino and an electron. Here we replace the neutrino in Fig. 1 by the electron-neutrino and the lepton l by the electron. Fig. 3 shows the corresponding vertex.

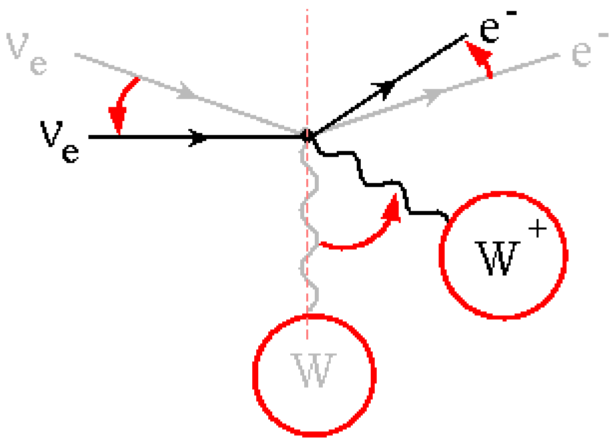
Fig. 3: The vertex of a weak interaction between an electron-neutrino and an electron.



As we can see in Fig. 3, the W-Boson is shown without charge. The decision upon its charge is made, after we have rotated the arms of the vertex so, that it corresponds to the interaction we want.

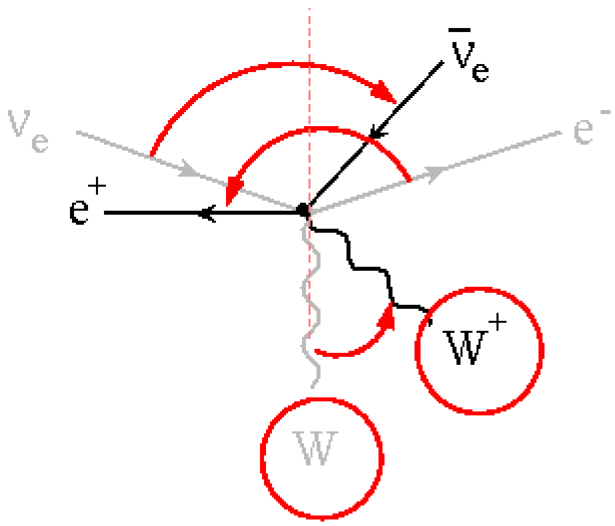
Assume that want to get the vertex for the interaction of an electron neutrino producing an electron and a virtual W-Boson. Then we have to rotate the arms with the arrows only a bit. But as the incoming charge is zero, the W-Boson must carry a positive charge to compensate the charge of the electron. Fig. 4 shows the corresponding procedure and resulting vertex.

Fig. 4: The arms of the standard electron vertex in Fig. 3 are rotated to give the vertex of an electron-neutrino interacting to produce a pair of an electron and a virtual W+ Boson.



Next we consider a positron interacting to produce a pair of antielectron-neutrino and a virtual W+ Boson. Fig. 5 shows the corresponding rotating procedure.

Fig. 5: The arms of the standard electron vertex in [Fig. 3](#) are rotated to give the vertex of a positron interacting to produce an antielectron-neutrino and a virtual W+ Boson.



It is easy to see, that the arms pass over the thin red separation line. When an arm passes over this line, ***the particle attached to this arm changes to its corresponding antiparticle***. Notice that the arm on the antielectron-neutrino points inwards. This is the convention for writing an antiparticle coming out of the vertex.

Problem

Proceeding in this way, we can get 6 different vertices for the electron/electronneutrino-interaction. But as there are 12 possible vertices available, we need 6 more vertices to complete the image.

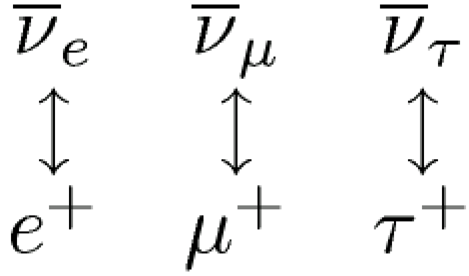
Example

Try to create using the above method the vertex associated the decay of a virtual W+ Boson emitted in the beta+ decay of a nucleus. You should get a W+ Boson incoming and positron and an electronneutrino exiting.

To succeed, you will need to put into the standard vertex in [Fig. 1](#) the antiparticles of the neutrino and the corresponding lepton.

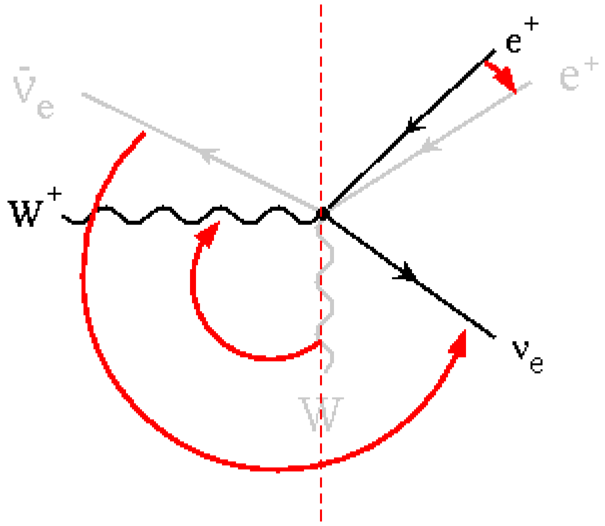
[Fig. 6](#) shows the table of antileptons, between which interactions are allowed.

Fig. 6: Table of antilepton interactions.



The needed vertex for a beta+ decay is then received from the standard antielectron weak interaction vertex like shown in Fig. 7.

Fig. 7: Rotating the arms of a standard antielektron vertex to give the final vertex of a beta+ decay coming out of an atomic kernel.



Again you can see, that passing the vertical red line creates an inversion of the engaged particle.

Back to Feynman vertices   Back to Index page   Next page: the electromagnetic vertices

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13. Examples of particle interactions described in terms of Feynman vertices

1. neutron decays to a proton, electron and an anti-electron neutrino
2. pi-plus decays to mu-plus and a muon neutrino
3. a positive muon decays to a muon antineutrino, a positron and an electron neutrino
4 K zero decays to a pi-minus and pi-plus via the weak interaction
5. lambda zero decays to a proton and a pi-minus via the weak interaction
6 a sigma plus decays to a proton and a pi-zero via the weak interaction

7. electron positron annihilation to two photons

8 xi-zero decays to a lambda zero and a pi-zero

9 positive kaon decays to three pions

10. sigma-zero decays to lambda zero and a photon

11. omega minus decays to xi-zero and a negative pion

12. positive kaon interacts with a proton to produce a neutral kaon and a delta++

13. antiproton interacts with a proton to produce a neutron and an antineutron

14. omega-minus decays to xi-zero, an electron and an electron antineutrino

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Example 1

$n \rightarrow p + e^- + \bar{\nu}_e$

In this case a neutron decays to a proton, an electron and an anti-neutrino via the weak interaction.

The quark analysis shows:

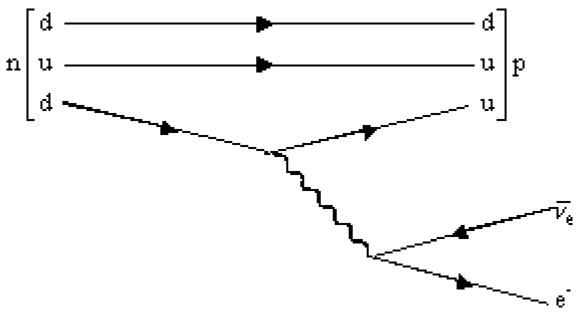
$n \rightarrow p + e^- + \bar{\nu}_e$

d→d

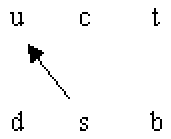
u→u

d→u with the creation of an electron and an anti-neutrino.

The corresponding Feynman diagram will be:



This is a weak decay of the down quark. It is an allowed vertical change in the same quark generation.



The Feynman diagram for the d to u transition is a combination of quark-W vertex and same generation lepton W vertex.

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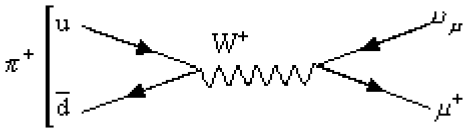
Example 2

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

In this example the up and the antidown quarks in the pi-plus annihilate to produce a W^+. The W^+ then materialises the lepton-antilepton pair.



The Feynman diagram is a simple combination of a quark weak vertex and a lepton-weak vertex. The quarks come form the same generation. Similarly, the leptons are a first generation pair.

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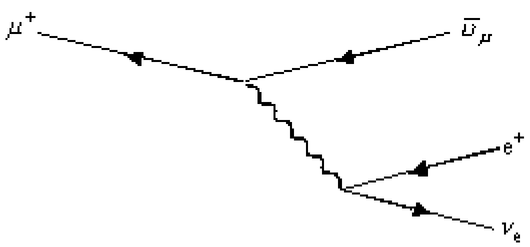
Example 3

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

In this example the positive muon emits a W^+ and transforms to a muon antineutrino. The W^+ then materialises a lepton-antilepton pair from the first generation of the antilepton family.



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Example 4

$K^{\circ} \rightarrow \pi^{+} + \pi^{-}$

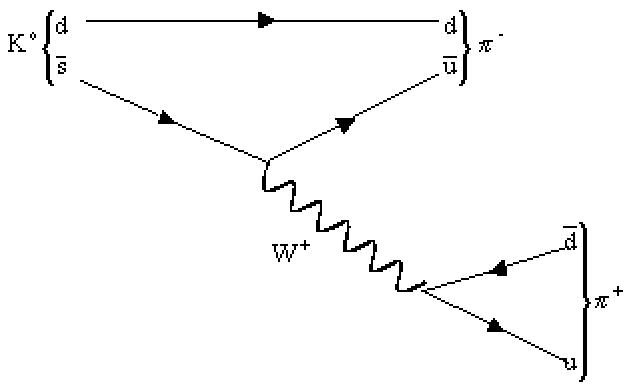
In this case a kaon-zero decays to a pi-minus and pi-plus via the weak interaction.

The quarks analysis shows:

$K^{\circ} \rightarrow \pi^{+} + \pi^{-}$

$d \rightarrow d$

$\bar{s} \rightarrow \bar{u}$ with the creation of an antidown - up pair.



This is a weak decay of the anti-strange quark. It is an allowed diagonal change between anti-quark generations.

The Feynman diagram shows a combination of an antiquark-weak vertex and a quark-weak vertex.

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Example 5

In this case a lambda zero decays to a proton and a pi-minus via the weak interaction.

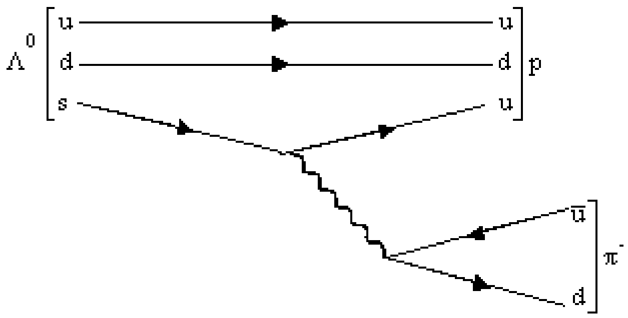
The quark analysis shows:

$u \rightarrow u$

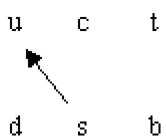
$d \rightarrow d$

$s \rightarrow u$ with the creation of a down - antiup pair.

The corresponding Feynman diagram will be:



This is a weak decay of the strange quark. It is an allowed diagonal change between quark generations.



The Feynman diagram for the s to u transition is a combination of two quark-W vertices. The pion is derived from a same generation quark weak vertex

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Example 6

$\Sigma^+ \rightarrow p + \pi^0$

In this case a Sigma plus decays to a proton and a pi-zero via the weak interaction.

The quark analysis shows:

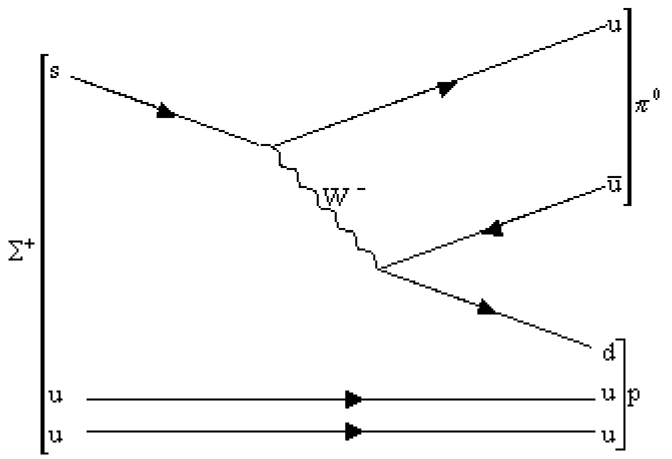
$$\Sigma^+ \rightarrow p + \pi^0$$

u → u

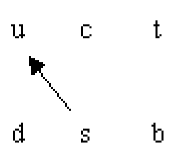
u → u

s → u   with the creation of a down - antiup pair.

The corresponding Feynman diagram will be:



This is a weak decay of the strange quark. It is an allowed diagonal change between quark generations.



The Feynman diagram for the s to u transition is a combination of two quark-W vertices.

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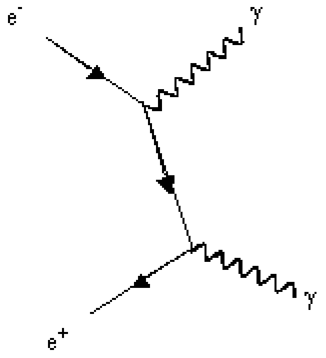
Example 7

$e^{+} + e^{-} \rightarrow \gamma + \gamma$

This is an annihilation of a positron and an electron.



The electron emits a real photon and becomes a virtual electron. This virtual electron then annihilates with the positron with the emission further photon. It is a combination of two electromagnetic-lepton vertices.

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Example 8

$\Xi^0 \rightarrow \Lambda^0 + \pi^0$

A xi-zero (uss) decays into a lambda zero (uds) and a pi zero ($u\bar{u}$)

The quark analysis shows:

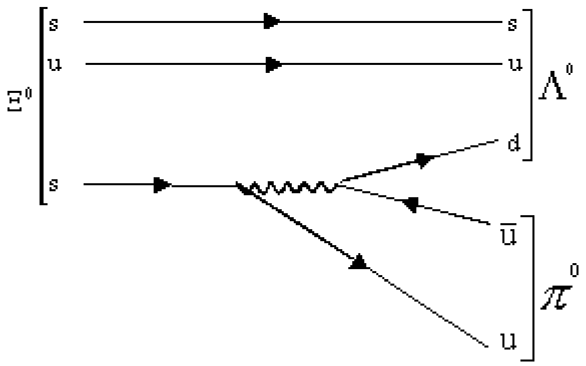
$\Xi^0 \rightarrow \Lambda^0 + \pi^0$

s $\rightarrow$ s

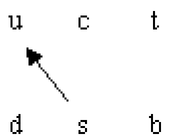
u $\rightarrow$ u

s $\rightarrow$ u with the creation of a down-antiup pair.

The corresponding Feynman diagram will be:

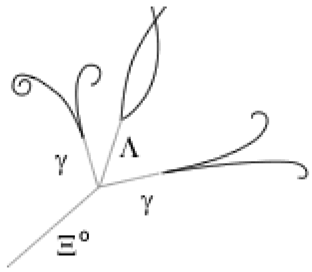


This is a weak decay of the strange quark. It is an allowed diagonal change between quark generation:



We also can see a quark weak vertex leading to a anti-up and a down quark.

This event involves only neutral particles and you may think that it could never be "seen" in a bubble chamber picture. BUT...



The signalled tracks in the picture above shows the xsi zero decay, in the bubble chamber picture of the discovery of omega minus! The two gammas come from pi zero disintegration!

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Example 9

$K^+ \to \pi^+ + \pi^+ + \pi^-$

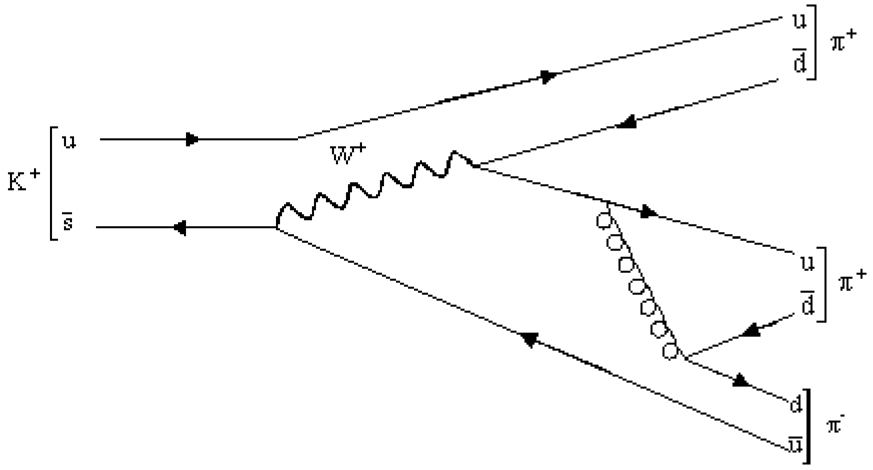
In this case a kaon-plus decays to a pi-minus and two pi-plus via the weak interaction and a gluon.

The quark analysis shows:

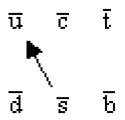
$K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$

$u \rightarrow u$

$\bar{s} \rightarrow \bar{u}$ and a W^+



This is a weak interaction of the anti-strange quark to an anti-up quark with the creation of a W-plus. The W-plus decays and an anti-down quark and an up quark are created. A gluon is created and materialises a down quark and an anti-down quark.



The anti-strange to anti-up vertex is an allowed diagonal change between antiquark generations.

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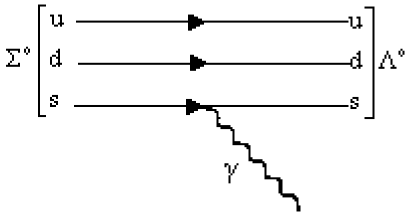
Example 10

$\Sigma^0 \rightarrow \Lambda^0 + \gamma$

In this case, one of the quarks in the sigma-zero emits a photon. It is a simple electromagnetic vertex.



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Example 11

$\Omega^- \rightarrow \Xi^0 + \pi^-$

A omega minus (sss) decays into a xsi zero (uss) and a pi minus.

The quark analysis shows:

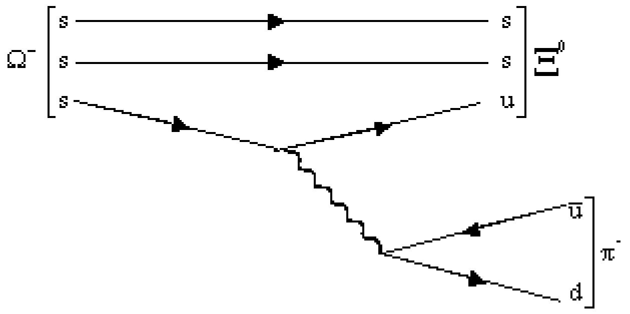
$\Omega^- \rightarrow \Xi^0 + \pi^-$

s $\rightarrow$ s

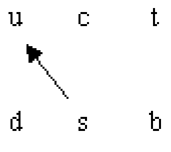
s $\rightarrow$ s

s $\rightarrow$ u with the creation of a down-antiup pair.

The corresponding Feynman diagram will be:



This is a weak decay of the strange quark. It is an allowed diagonal change between quark generation:



We also can see a quark weak vertex leading to a anti-up and a down quark.

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Example 12

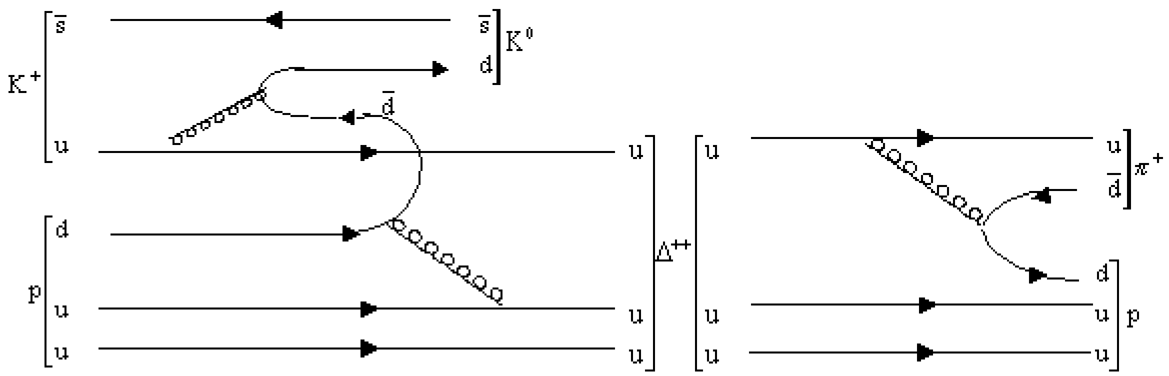
$K^{+} + p \rightarrow K^{0} + \Delta^{++}$

In this case there is a collision between a positive kaon (K^{+}) and a proton (p)

In the strong interaction a neutral kaon (K^{0}) and an excited state (Δ^{++}) are produced.

The Δ^{++} then decays to a proton and a positive pion.

The suggested Feynman diagram might be:



This is a strong interaction and involves quark-gluon vertices only.

The quark analysis shows:

the up quark of the kaon emits a gluon and the gluon materializes into a down quark and an antidown quark

the down quark of the proton annihilates with the antidown quark emitting a gluon

the three up quarks recombine as an excited state Δ^{++}

then....

an up quark of the excited state emits a gluon and the gluon materializes into a down quark and an antidown quark

an up quark and the antidown quark recombine as a positive pion

two up and the down quark recombine as a proton.

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Example 13

$\bar{p} + p \rightarrow \bar{n} + n$

In this case there is a collision between a proton (p) and an antiproton (p).

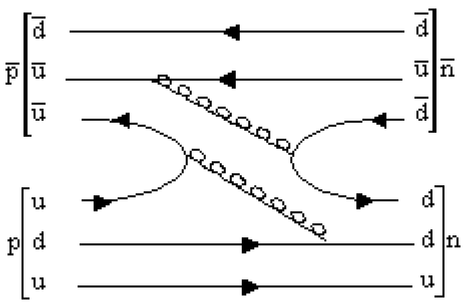
In the final state a neutron and an antineutron are produced.

The quark analysis shows:

the antiup quark of the antiproton annihilates with the up quark of the proton emitting a gluon.

the antidown quark of the antiproton emits a gluon and the gluon materialize into an antidown and a down quark

The corresponding Feynman diagram will be:



This is a strong interaction and involves quark gluon vertices only.

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Example 14

$\Omega^- \rightarrow \Xi^0 + e^- + \bar{\nu}_e$

In this case an Omega minus decays to a xi- zero, an electron and electron anti-neutrino via the weak interaction.

The quark analysis shows:

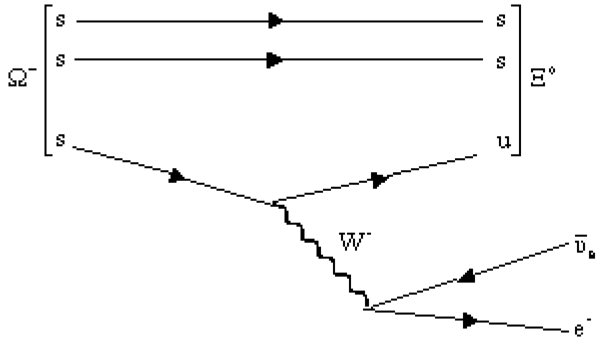
$\Omega^- \rightarrow \Xi^0 + e^- + \bar{\nu}_e$

s $\rightarrow$ s

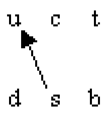
s $\rightarrow$ s

s $\rightarrow$ u with the creation of an electron - antineutrino pair.

The corresponding Feynman diagram will be:



This is a weak decay of the strange quark. It is an allowed diagonal change between quark generations.



The Feynman diagram illustrates that the reaction is a combination of a quark weak vertex and a weak-lepton vertex.

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http://commons.wikimedia.org/wiki/Category:Feynman_diagrams