



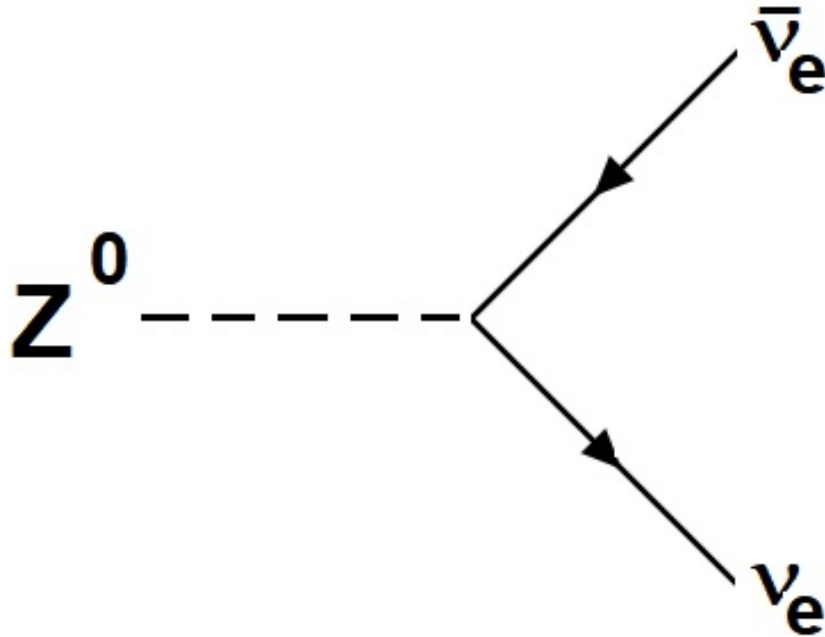
PARTICLE TRANSFORMATIONS

Annotated for teachers

Gauge boson decays

Feynman Diagram:

Decay B-01



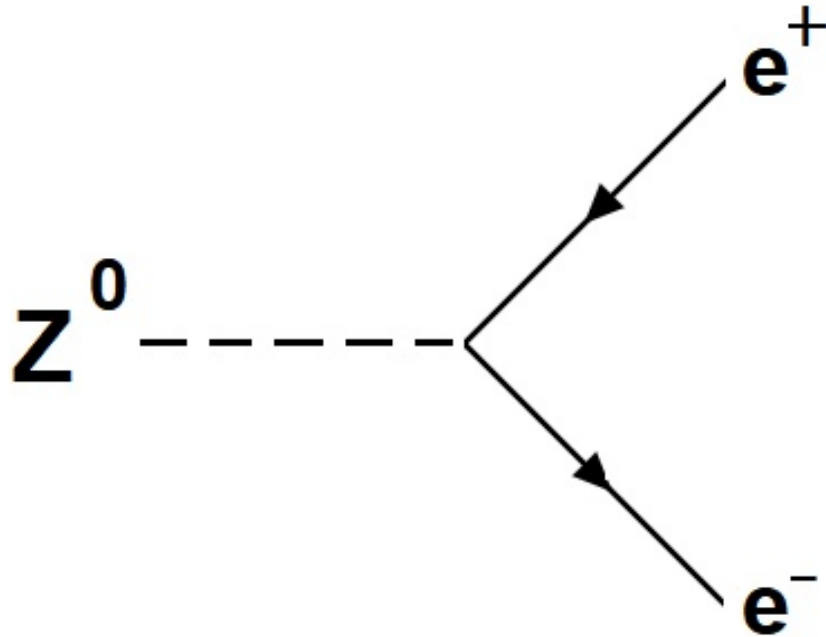
A Z boson transforms into an antielectron neutrino and an electron neutrino.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=91200 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=-1+1=0, mass=almost zero Electron number=-1+1=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-02



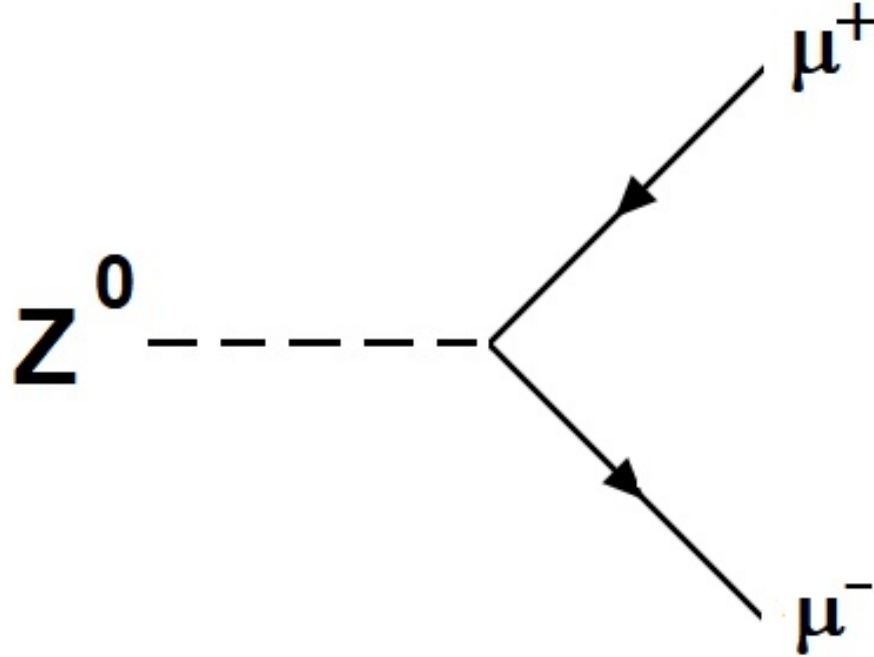
*A Z boson
transforms into a
positron and an
electron.*

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=91200 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=1.022 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-03



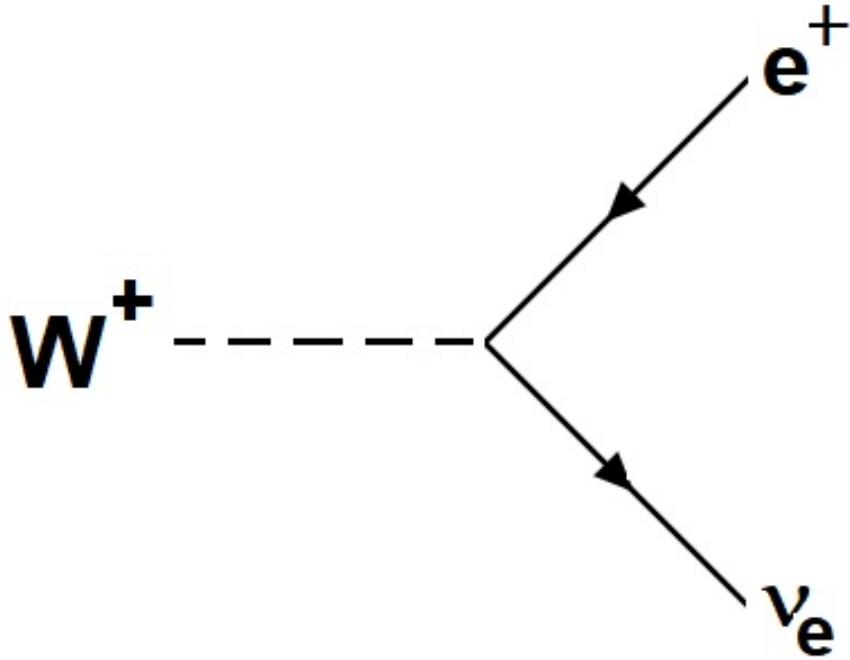
*A Z boson
transforms into an
antimuon and a muon.*

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=91200 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=212 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-04



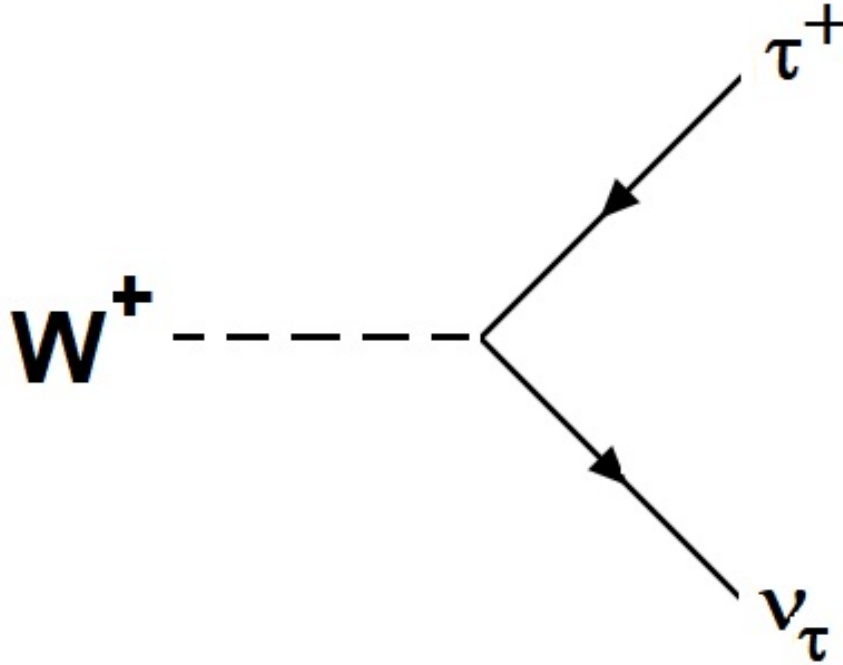
A W^+ boson transforms into a positron and an electron neutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=0, mass=80400 MeV Electron number=0 Muon number=0 Tau number=0	Q=+1, lepton number=0, mass=0.511 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-05



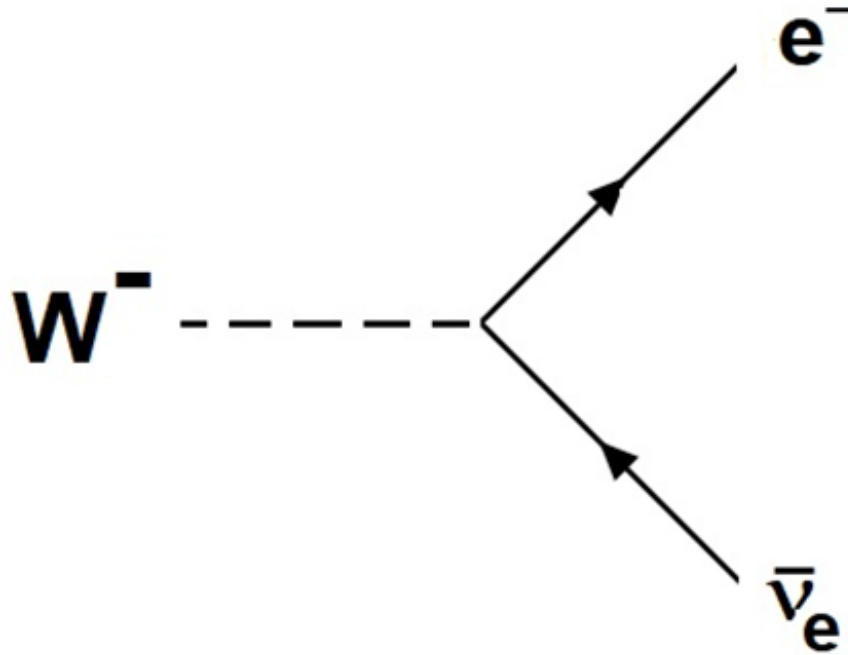
A W^+ boson transforms into an antitau and a tau neutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=0, mass=80400 MeV Electron number=0 Muon number=0 Tau number=0	Q=+1, lepton number=0, mass=1777 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-06



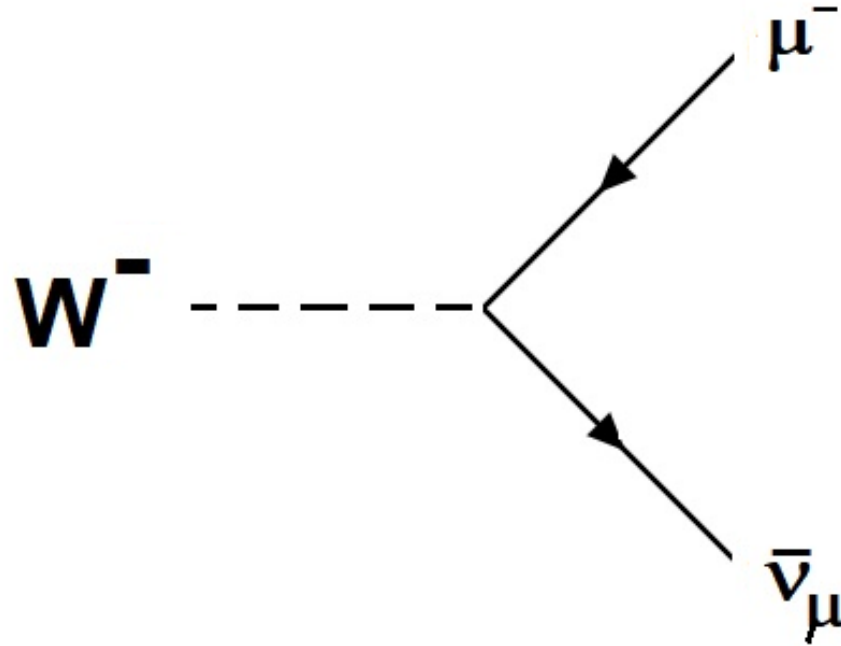
A W^- boson transforms into an electron and an electron antineutrino.

Scratchpad:

Before decay	After decay
Q=-1, lepton number=0, mass=80400 MeV Electron number=0 Muon number=0 Tau number=0	Q=-1, lepton number=0, mass=0.511 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay B-07



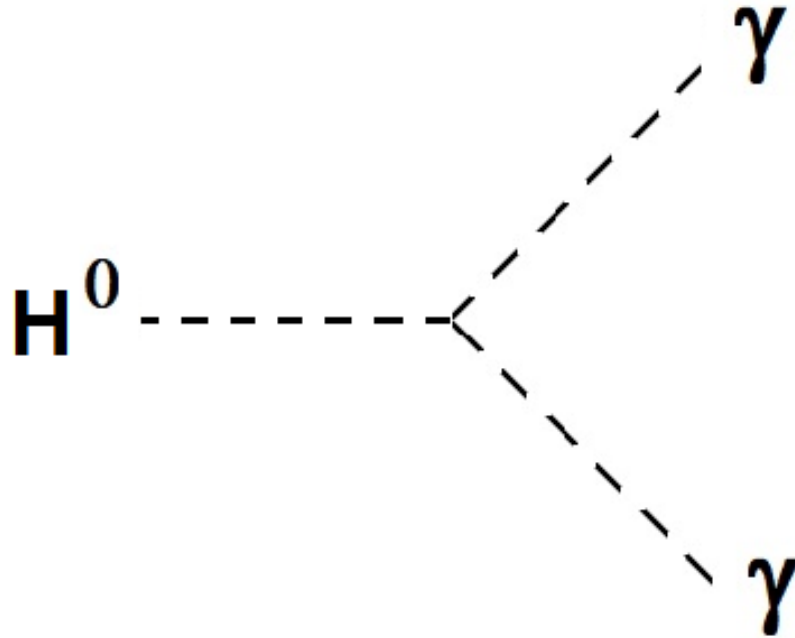
A W^- boson transforms into a muon and a muon antineutrino.

Scratchpad:

Before decay	After decay
$Q=-1$, lepton number=0, mass=80400 MeV	$Q=-1$, lepton number=0, mass=106 MeV

Feynman Diagram:

Decay B-08



*A Higgs boson
transforms into two
photons.*

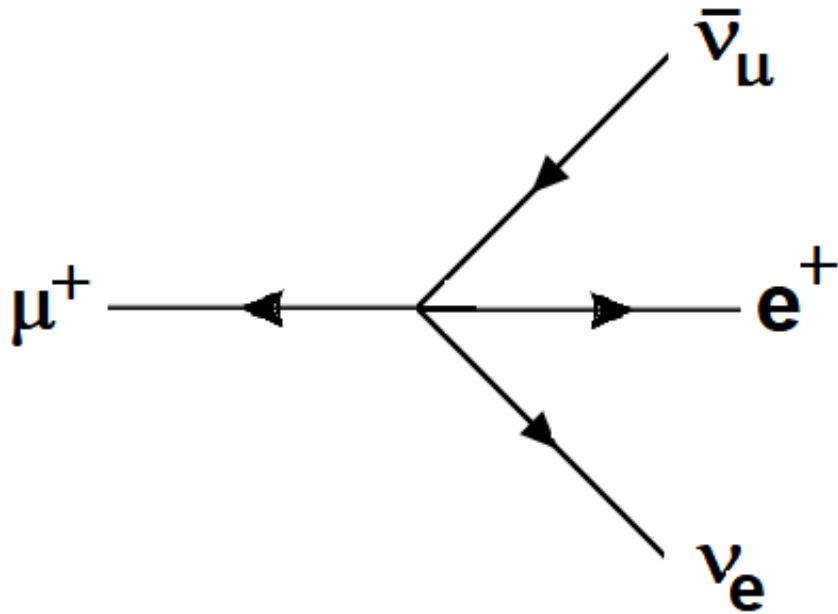
Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=125000 MeV	Q=0, lepton number=0, mass=0

Lepton decays

Feynman Diagram:

Decay L-01



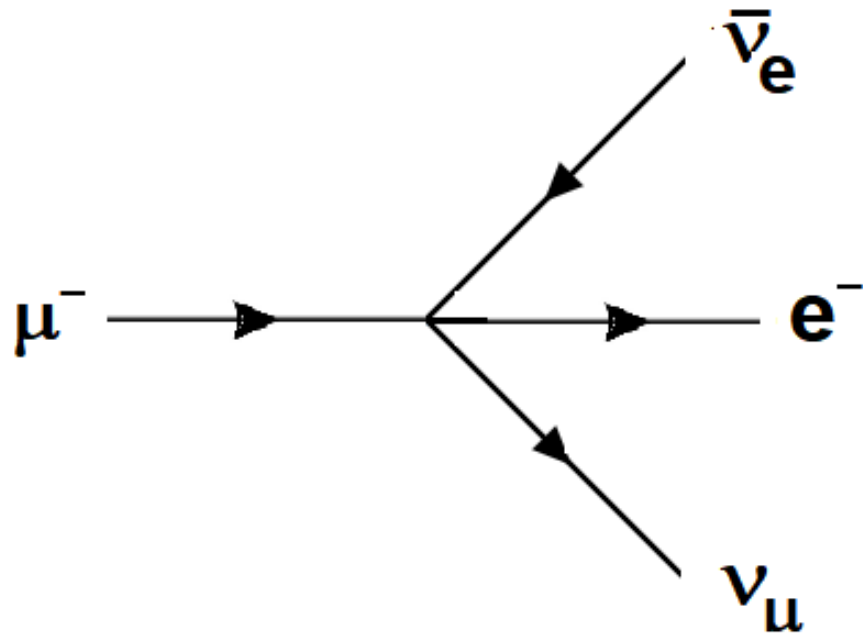
An antimuon transforms into an antimuon neutrino, a positron, and an electron neutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=-1, mass=106 MeV Gen=2 Electron number=0 Muon number=-1 Tau number=0	Q=+1, lepton number=-1-1+1=-1, mass=0.511 MeV Gen=2,1,1 Electron number=-1+1=0 Muon number=-1 Tau number=0

Feynman Diagram:

Decay L-02



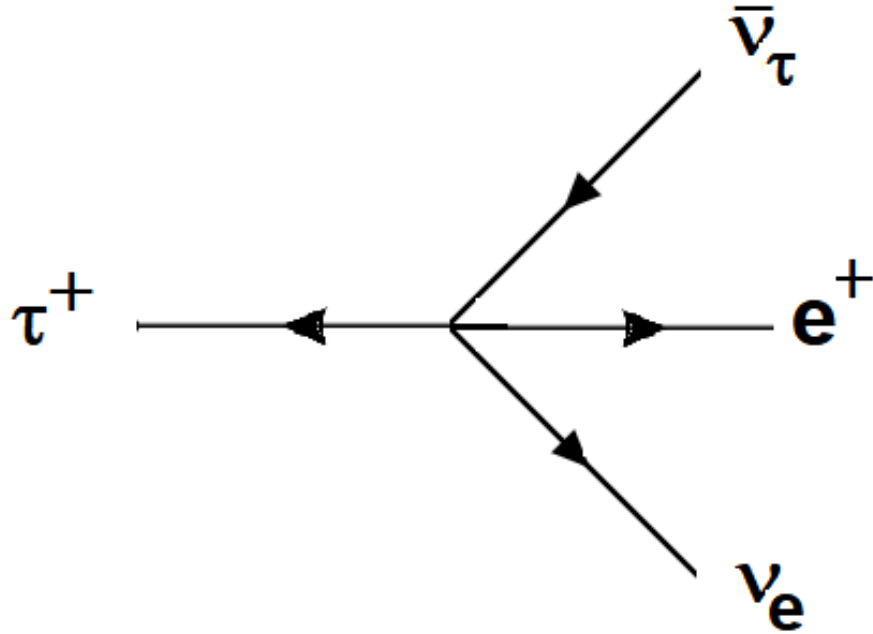
A muon transforms into an electron antineutrino, an electron, and a muon neutrino.

Scratchpad:

Before decay	After decay
Q=-1, lepton number=+1, mass=106 MeV Gen=2 Electron number=0 Muon number=-1 Tau number=0	Q=-1, lepton number=+1, mass=0.511 MeV Gen=1,1,2 Electron number=0 Muon number=-1 Tau number=0

Feynman Diagram:

Decay L-03



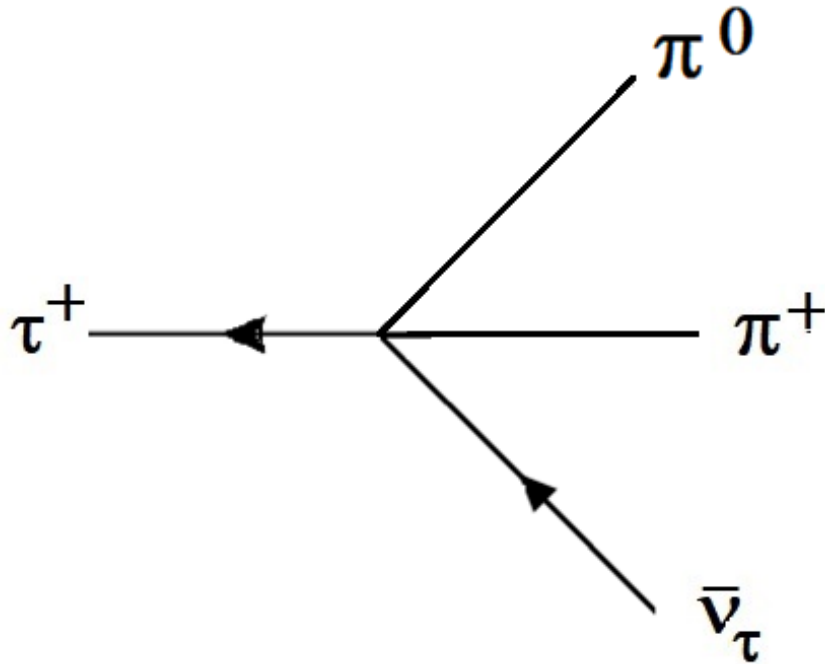
An antitau transforms into a tau antineutrino, a positron, and an electron neutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=-1, mass=1777 MeV Gen=3 Electron number=0 Muon number=0 Tau number=-1	Q=+1, lepton number=-1, mass=0.511 MeV Gen=3,1,1 Electron number=0 Muon number=0 Tau number=-1

Feynman Diagram:

Decay L-04



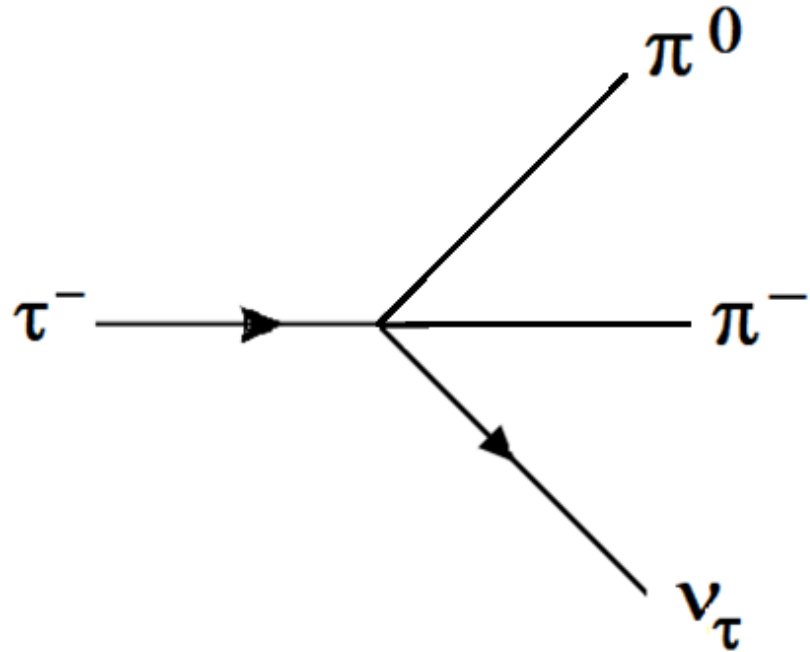
An antitau transforms into a neutral pion, a positive pion, and a tau antineutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=-1, mass=1777 MeV Gen=3 Electron number=0 Muon number=0 Tau number=-1	Q=+1, lepton number=-1, mass=275 MeV Gen=N/A, N/A, 3 Electron number=0 Muon number=0 Tau number=-1

Feynman Diagram:

Decay L-05



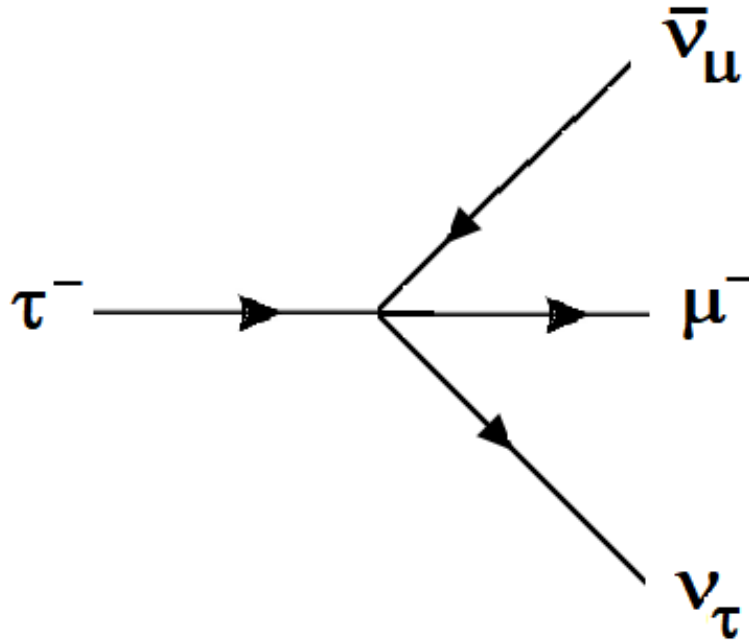
A tau transforms into a neutral pion, a negative pion and a tau neutrino.

Scratchpad:

Before decay	After decay
Q=-1, lepton number=+1, mass=1777 MeV Gen=3 Electron number=0 Muon number=0 Tau number=+1	Q=-1, lepton number=+1, mass=275 MeV Gen=N/A, N/A, 3 Electron number=0 Muon number=0 Tau number=+1

Feynman Diagram:

Decay L-06



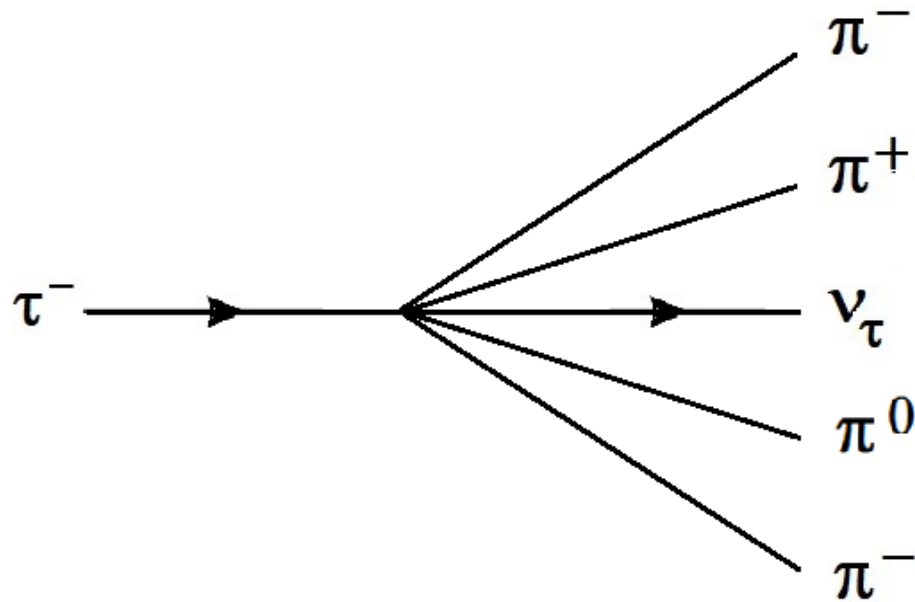
*A tau transforms
into a muon
antineutrino, a muon
and a tau neutrino.*

Scratchpad:

Before decay	After decay
Q=-1, lepton number=+1, mass=1777 MeV Gen=3 Electron number=0 Muon number=0 Tau number=+1	Q=-1, lepton number=+1, mass=106 MeV Gen=2,2,3 Electron number=0 Muon number=0 Tau number=+1

Feynman Diagram:

Decay L-07



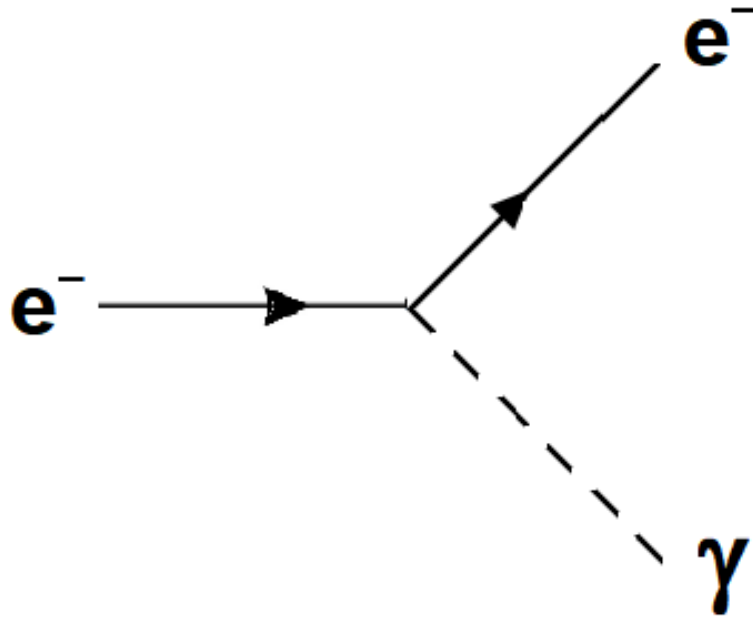
An tau transforms into a neutral pion, a positive pion, two negative pions, and a tau neutrino.

Scratchpad:

Before decay	After decay
Q=-1, lepton number=+1, mass=1777 MeV Gen=3 Electron number=0 Muon number=0 Tau number=+1	Q=-1, lepton number=+1, mass=555 MeV Gen=N/A, N/A, 3, N/A, N/A Electron number=0 Muon number=0 Tau number=+1

Feynman Diagram:

Decay L-08



*Not really a decay:
an electron radiates
a photon. This
occurs when
something causes
the electron to lose
momentum.*

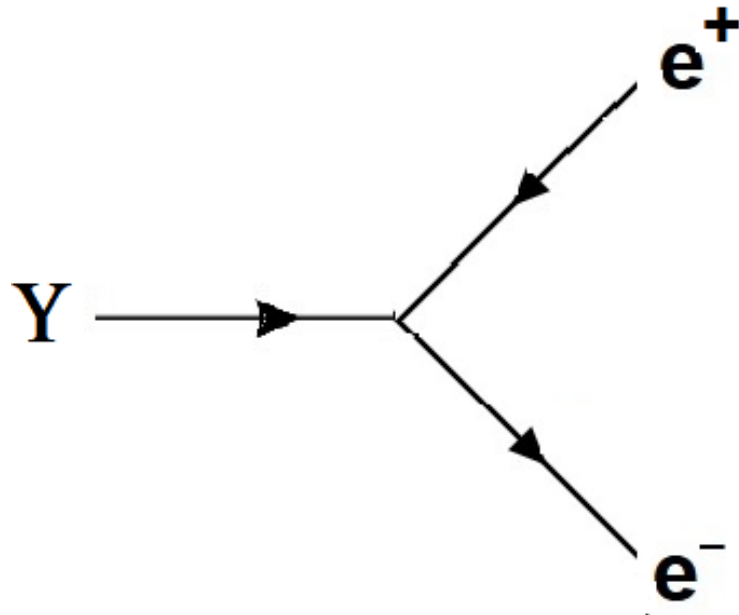
Scratchpad:

Before decay	After decay
Q=-1, lepton number=+1, mass=0.511 MeV Gen=1 Electron number=+1 Muon number=0 Tau number=0	Q=-1, lepton number=+1, mass=0.511 MeV Gen=1, N/A Electron number=+1 Muon number=0 Tau number=0

Meson decays

Feynman Diagram:

Decay Q-01



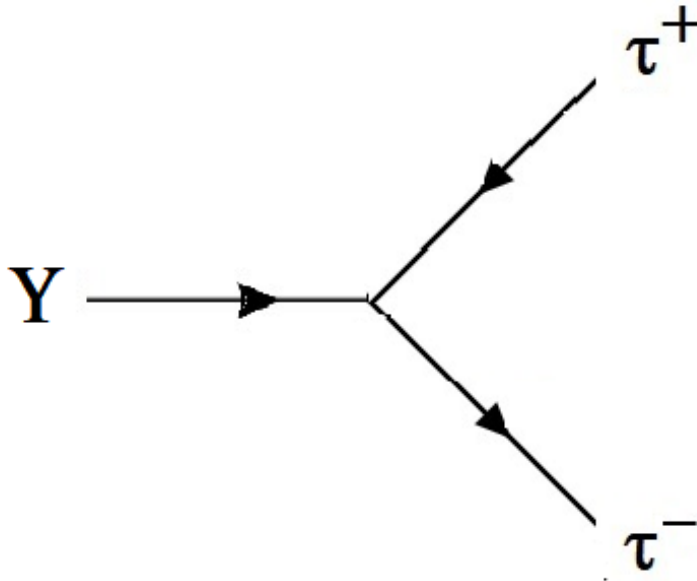
An upsilon meson transforms into a positron and an electron.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=9460 MeV Electron number=0 Muon number=0 Tau number=0	Q=+1-1=0, lepton number=-1+1=0, mass=0.511 MeV + 0.511 MeV = 1.022 MeV Electron number=-1+1=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-02



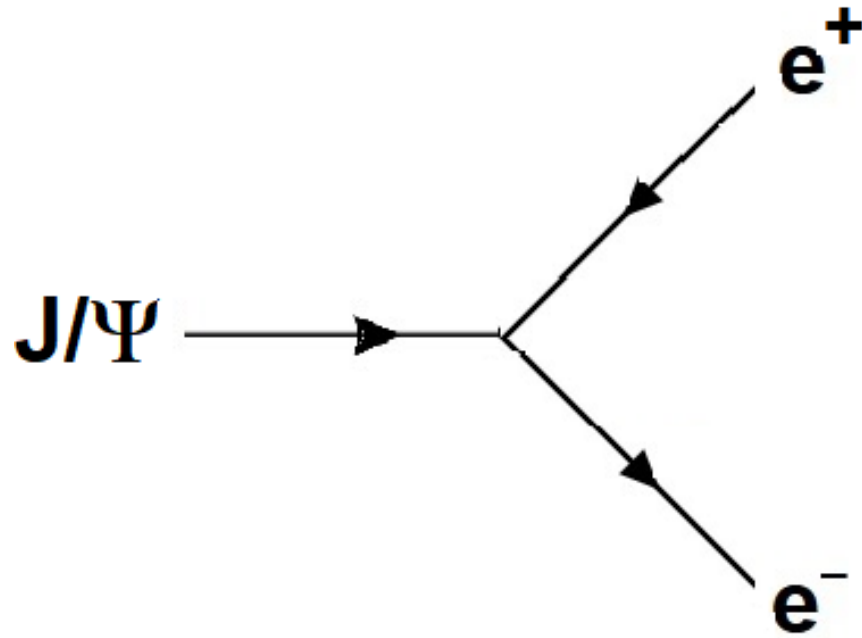
An upsilon meson transforms into an antitau and a tau.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=9460 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=3544 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-03



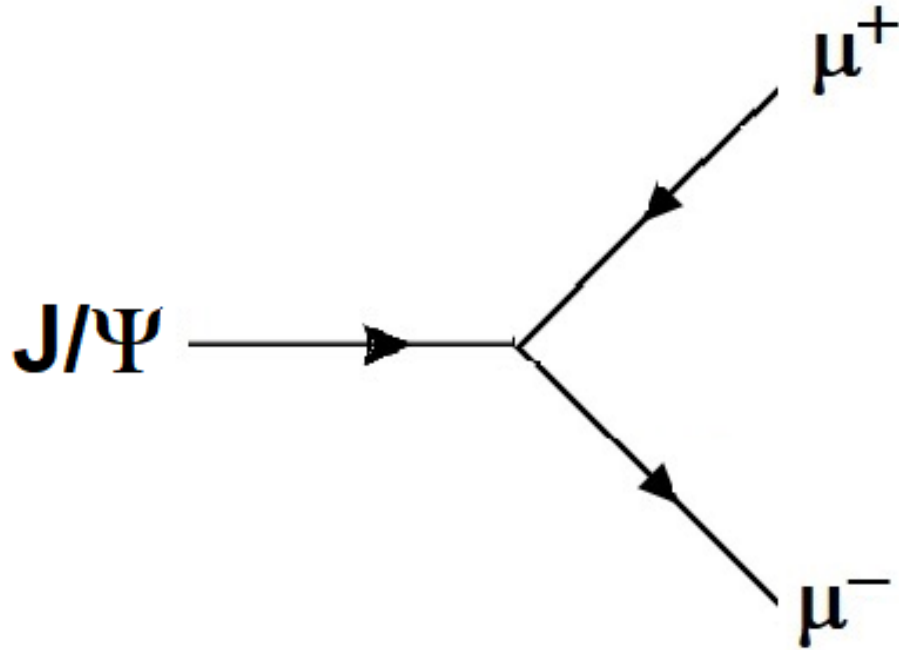
A J/Psi meson transforms into a positron and an electron.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=3096 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=1.022 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-04



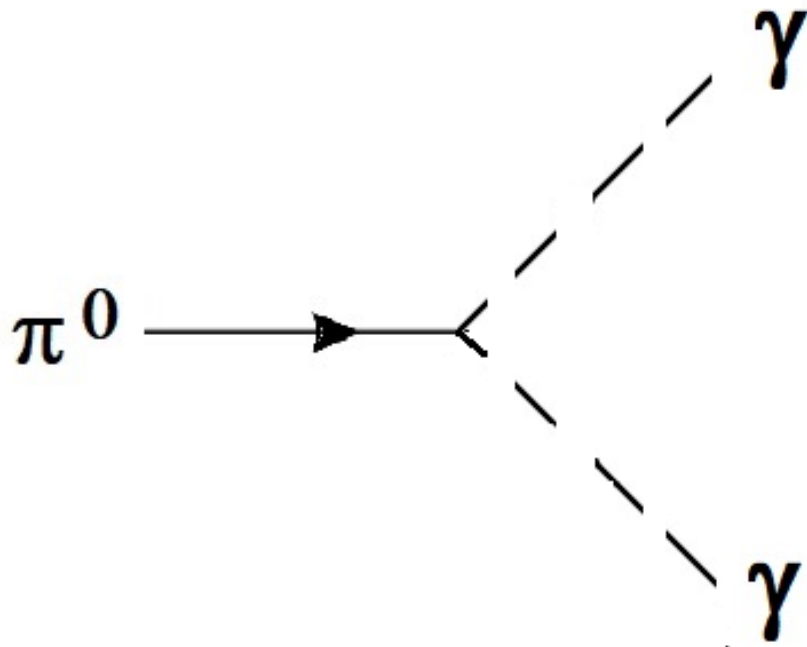
A J/Psi meson transforms into an antimuon and a muon.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=3096 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=212 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-05



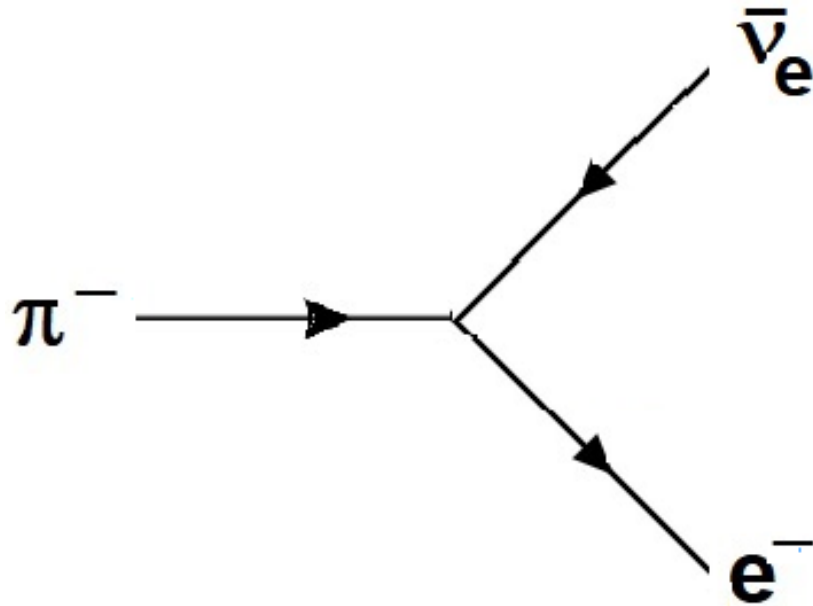
*A neutral pion
transforms into two
photons.*

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=1690 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=0 Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-06



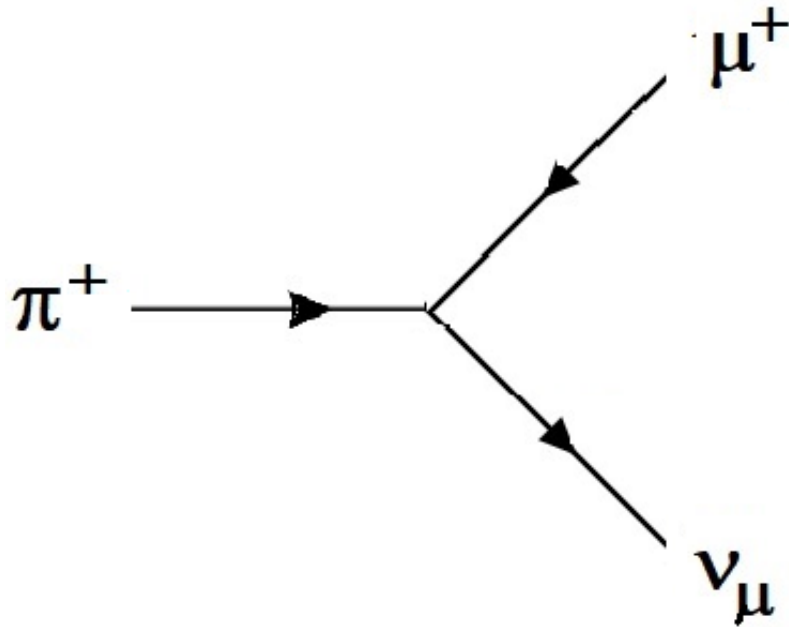
A negative pion transforms into an electron antineutrino and an electron.

Scratchpad:

Before decay	After decay
Q=-1, lepton number=0, mass=1680 MeV Electron number=0 Muon number=0 Tau number=0	Q=-1, lepton number=0, mass=0.511 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-07



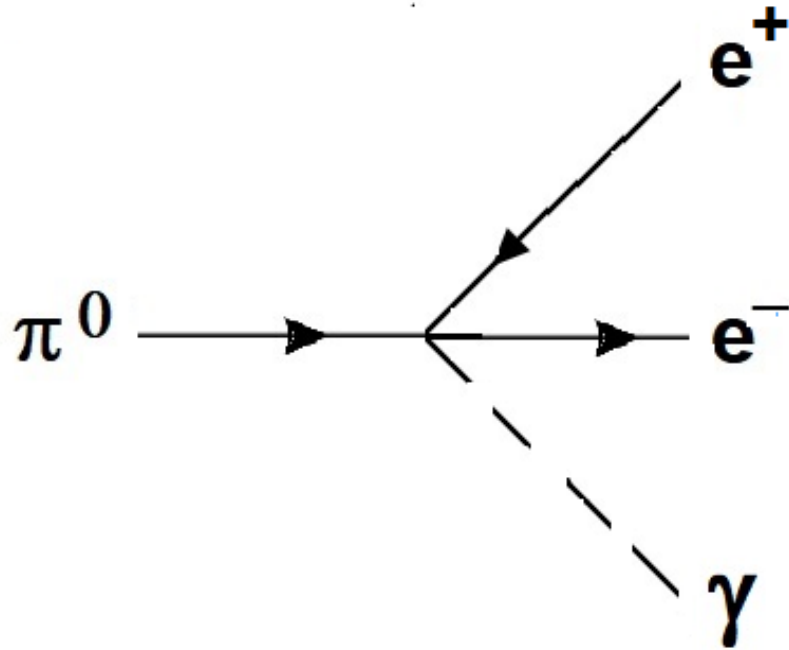
A positive pion transforms into an antimuon and a muon neutrino.

Scratchpad:

Before decay	After decay
Q=+1, lepton number=0, mass=140 MeV Electron number=0 Muon number=0 Tau number=0	Q=+1, lepton number=0, mass=106 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Q-08



A neutral pion transforms into a positron, an electron, and a photon.

Scratchpad:

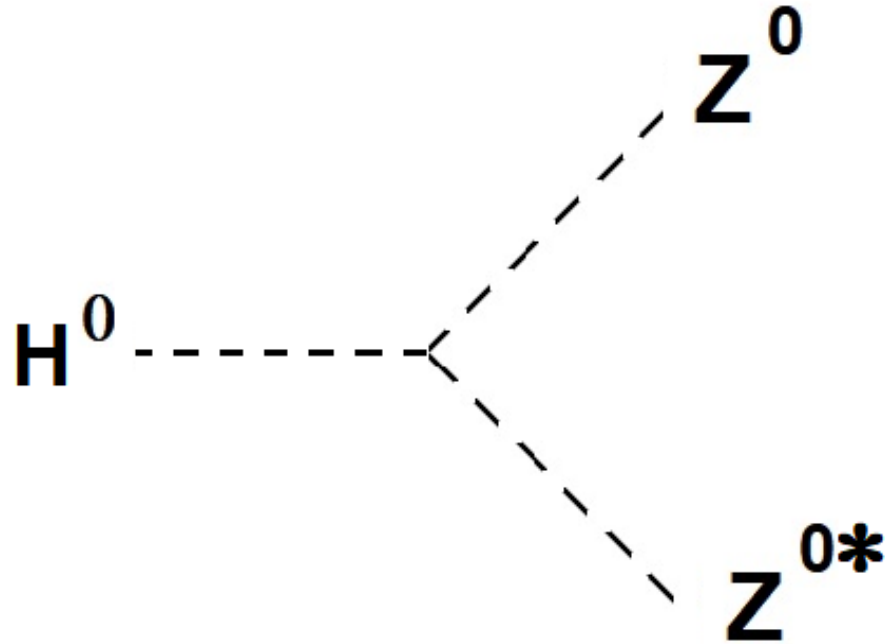
Before decay	After decay
Q=0, lepton number=0, mass=135 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=1.022 MeV Electron number=0 Muon number=0 Tau number=0

Zoo

of interesting and challenging interactions
(some decays, some not)

Feynman Diagram:

Decay Z-01



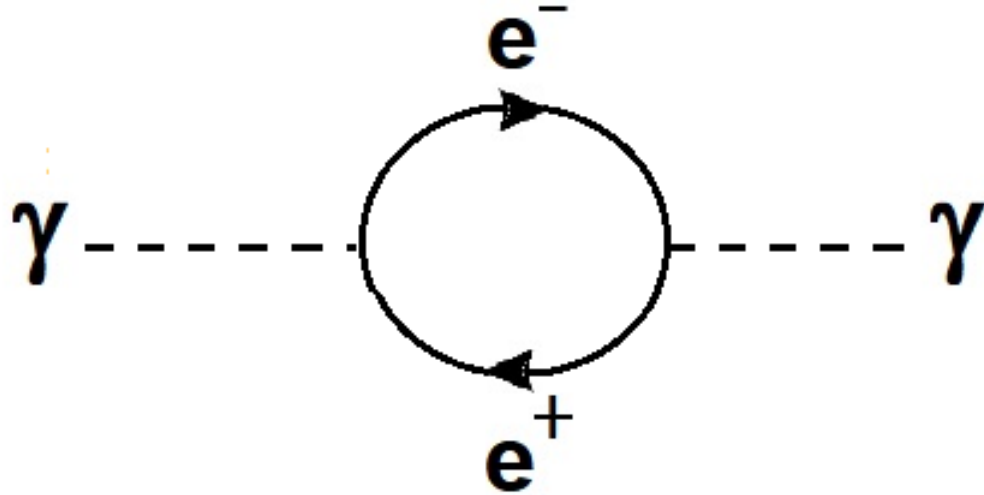
*A Higgs boson transforms into a Z boson and a "virtual" or "off-shell" Z boson (hence the *) which is rare and has a smaller mass than usual for a very short time. Both Z bosons decay promptly.*

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=12500 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=indeterminate Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-02



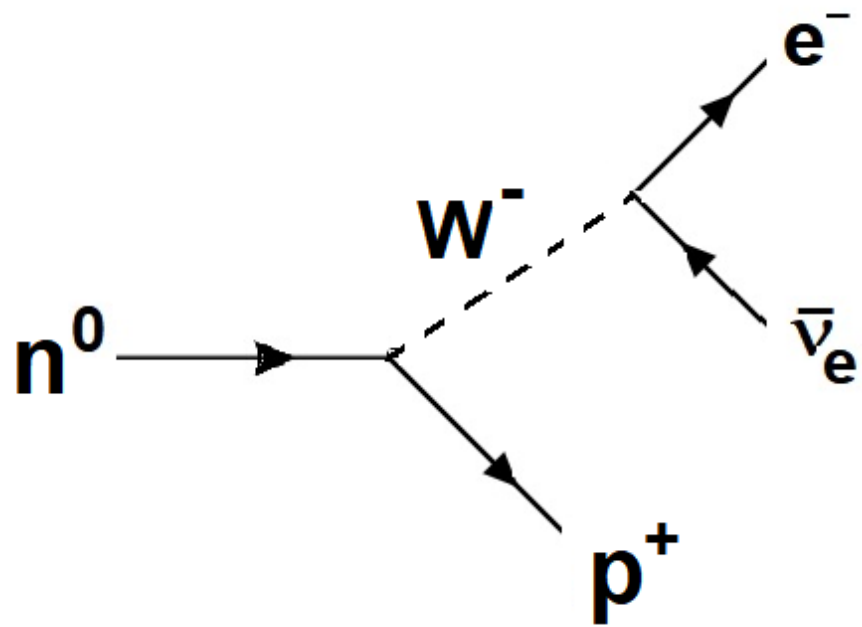
A photon transforms very briefly into an electron-positron pair which promptly comes back together as a photon.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=0 Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=0 Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-03



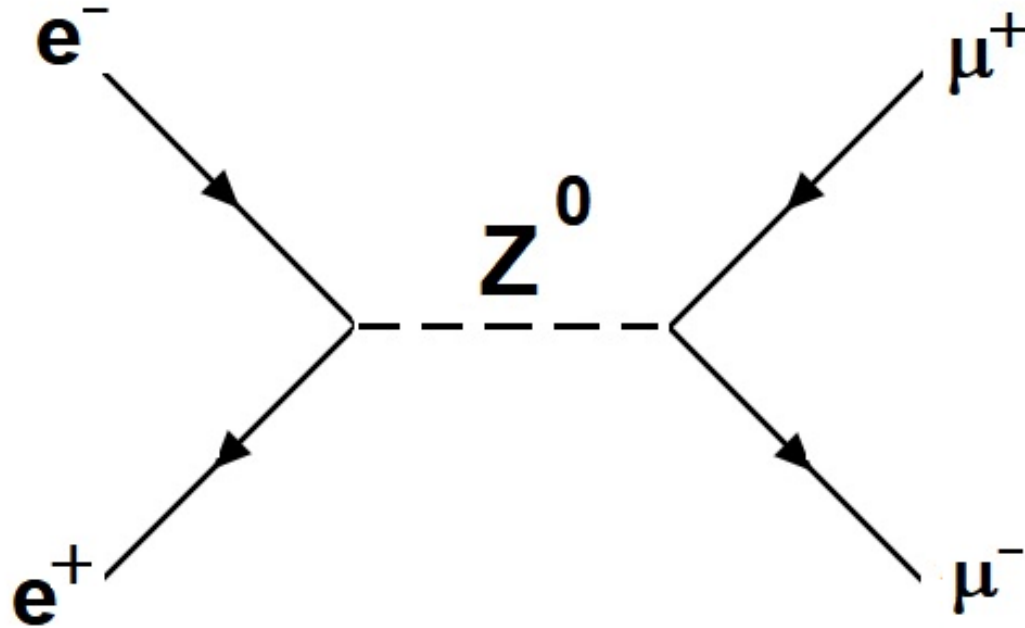
Beta decay, often represented as $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$ but is actually a weak interaction, in which a down quark in the neutrino emits a W^- , converting the down to an up and the neutron to a proton. The W^- then decays into an electron and an electron antineutrino.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=940 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=938.5 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-04



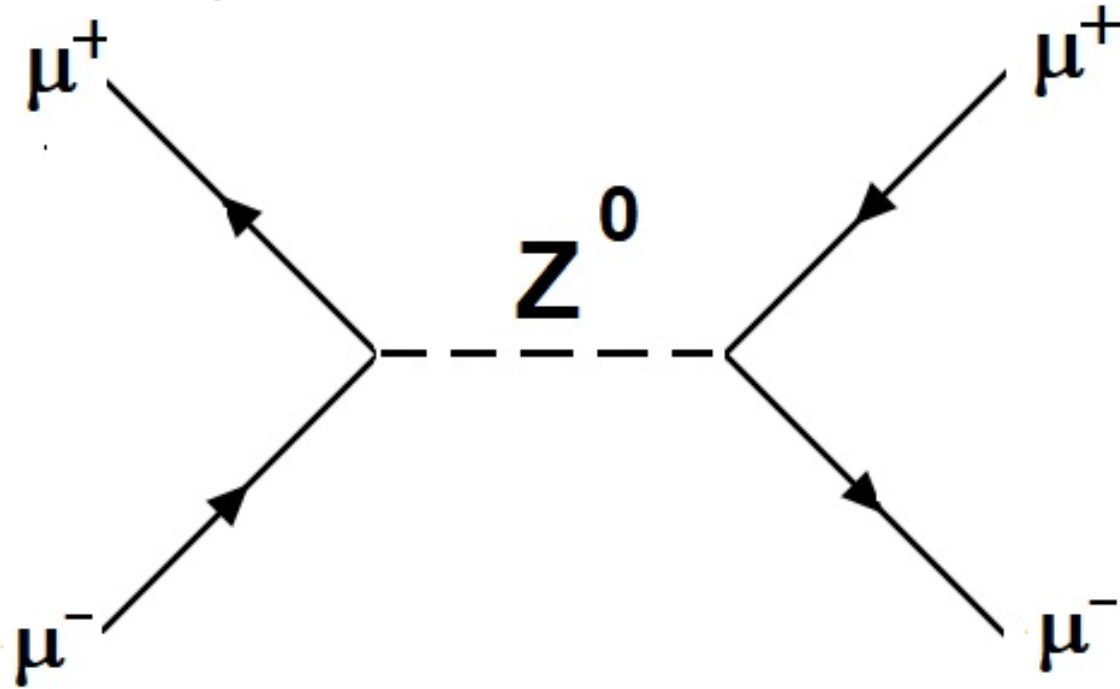
In the International Linear Collider, during its test run, an electron and a positron collide to form a Z boson, which decays into an antimuon and a muon. The energy of the collision converts to the mass of the Z^0 .

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=1.022 MeV Energy= ~ 91000 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=212 MeV Energy= ~ 91000 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-05



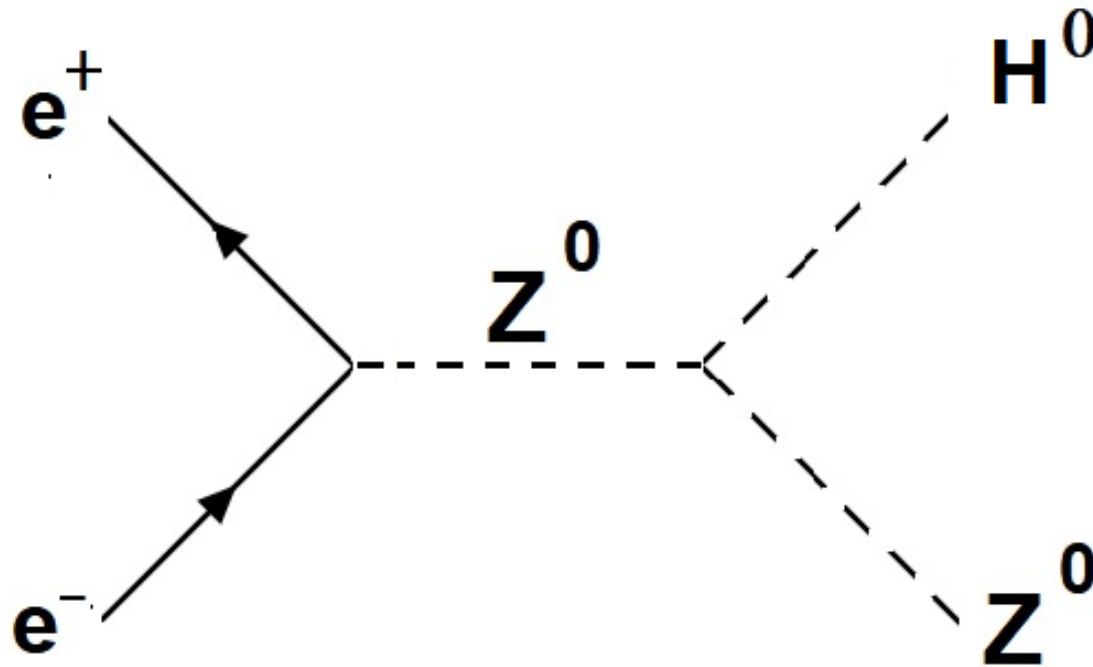
*Weak neutral current.
A muon-antimuon pair
undergoes a weak
interaction but is left
pretty much
unchanged.*

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=212 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass=212 MeV Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-06



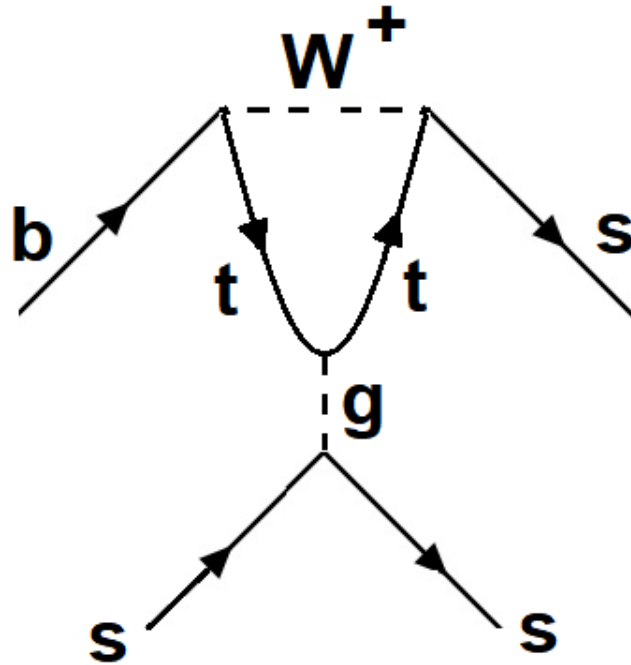
The expected main mechanism for making a Higgs boson in the International Linear Collider is creation of an energized Z boson which promptly radiates a Higgs. Think about what would be observed in this case.

Scratchpad:

Before decay	After decay
Q=0, lepton number=0, mass=1.022 MeV Energy \geq 216000 MeV Electron number=0 Muon number=0 Tau number=0	Q=0, lepton number=0, mass~216000 MeV Energy \geq 0 Electron number=0 Muon number=0 Tau number=0

Feynman Diagram:

Decay Z-06



Super-challenge: the Penguin diagram. In short, a strange quark has a strong interaction with a bottom quark changing into a strange quark via the weak interaction through a mediating top quark. Learn more at

<https://www.symmetrymagazine.org/article/june-2013/the-march-of-the-penguin-diagrams>.

Scratchpad:

Before decay	After decay
Q=-2/3, lepton number=0, mass=4300 MeV Electron number=0 Muon number=0 Tau number=0	Q=-2/3, lepton number=0, mass=200 MeV Electron number=0 Muon number=0 Tau number=0