Compare the three interactions

**Electromagnetic**
- Photon

**Weak**
- $Z, W^\pm$

**Strong**
- Gluons

The principle stays the same, only the players change:
- **Bosons** communicate interactions between fermions.
- **Bosons** characterize an interaction.
Pairs of fermions in the weak interaction

• Fermions form pairs for the weak interaction. While the electromagnetic interaction affects only a single fermion, the electron.

• The electron and the neutrino form a pair.

• The up quark and the down quark form a pair.
Triplets of fermions in the strong interaction

- Only quarks interact strongly.

- All quarks come in three colors: Red, Green, Blue

- The three colors add up to white.
Colored quarks

Quark Color Causes Strong Force (Nuclear Force)

In 1965 Moo-Young Han and Yoichiro Nambu suggested quarks possess color.

<table>
<thead>
<tr>
<th>Color</th>
<th>Anti-color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Anti-red = Cyan</td>
</tr>
<tr>
<td>Blue</td>
<td>Anti-blue = Yellow</td>
</tr>
<tr>
<td>Green</td>
<td>Anti-green = Magenta</td>
</tr>
</tbody>
</table>

The "color" attribute is not traditional color; the name is somewhat arbitrary, and almost as whimsical as the names of the quarks.

The three colors represent three charges. Equal charges repel.
Why 8 gluons?

Each gluon carries two colors in opposite directions.

The 8 gluons are formed from the $3 \times 3 = 9$ color combinations. One of these is excluded by the condition that color must be transferred. The sum of the three gluons in the left column would not transfer any color (only white). (Physics Today, August 2000, p. 22)
Why 3 bosons for the weak interaction?

The weak interaction can also be viewed in terms of color. Since the fermions form pairs (instead of triplets), we need 2 colors that add up to white (instead of 3), e.g. red and cyan.

The 3 bosons are formed from the $2 \times 2 = 4$ color combinations. One of these is excluded by the condition that color must be transferred. The sum of the two bosons in the left column would not transfer any color (only white).
Quark-gluon interaction

- A gluon transports the two colors of two quarks.
- Color is conserved during the interaction. This is reflected in a continuous stream of colored lines.
Interaction between quarks
Allowed combinations of quarks

Only colorless (white) combinations of quarks produce observable particles:

A) Three quarks: proton, neutron Red + Green + Blue

B) Quark + antiquark: pions Red + Cyan

Cyan = Anti-Red = Complementary Color
3 quarks: proton and neutron
Interaction between quarks in two protons

Only one quark interacts for each proton. The other quarks are spectators.
A single quark cannot be observed

- The strong interaction energy grows with distance. (It decreases for electromagnetism and gravity.)
- The strong interaction behaves like a rubber band: When the band is stretched, its energy increases.
- Once the band is stretched so far that its energy is enough to make a quark-antiquark pair, it breaks. A quark and an antiquark appear at the two ends.
- It is like Hercules fighting the multi-headed snake Hydra: For each head he cut off, two new heads grew back.
Why we can’t see a single quark

But a high energy quark can be detected indirectly by the trail of quark-antiquark pairs that it leaves behind (called a ‘jet’).