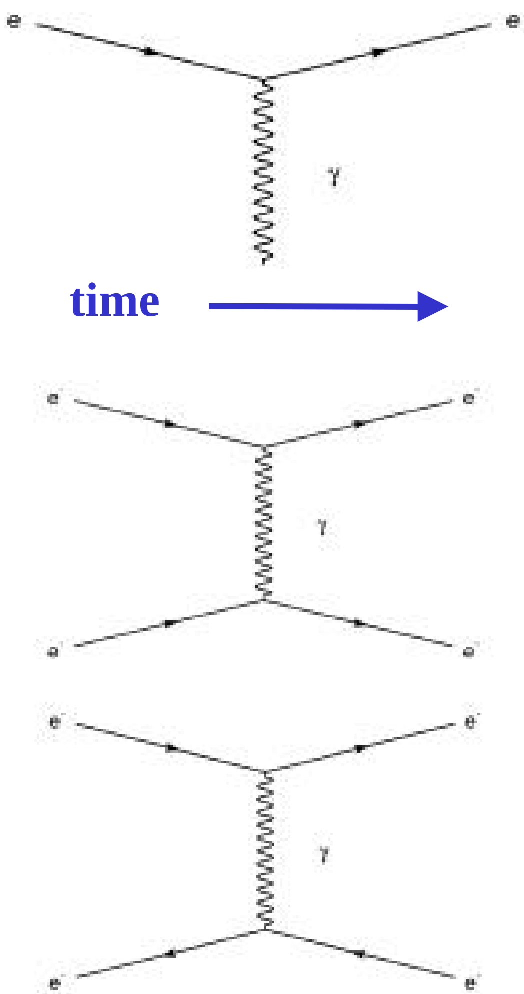
Introduction to Feynman Diagrams and Dynamics of Interactions

- All known interactions can be described in terms of forces forces:

– Strong	10	Chromodynamics
– Elecgtromagnetic	10^{-2}	Electrodynamics
– Weak	10^{-13}	Flavordynamics
– Gravitational	10^{-42}	Geometrodynamics

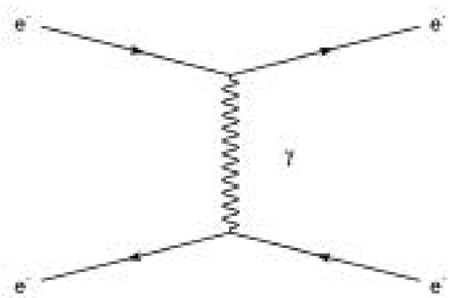
- Feynman diagrams represent quantum mechanical transition amplitudes, M, that appear in the formulas for cross-sections and decay rates.
- More specifically, Feynman diagrams correspond to calculations of transition amplitudes in perturbation theory.
- Our focus today will be on some of the concepts which unify and also which distinguish the quantum field theories of the strong, weak, and electromagnetic interactions.

Quantum Electrodynamics (QED)



- **The basic vertex shows the coupling of a charged particle (an electron here) to a quantum of the electromagnetic field, the photon. Note that in my convention, time flows to the right. Energy and momentum are conserved at each vertex. Each vertex has a coupling strength characteristic of the interaction.**
- **Moller scattering is the basic first-order perturbative term in electron-electron scattering. The invariant masses of internal lines (like the photon here) are defined by conservation of energy and momentum, not the nature of the particle.**
- **Bhabha scattering is the process electron plus positron goes to electron plus positron. Note that the photon carries no electric charge; this is a neutral current interaction.**

Adding Amplitudes



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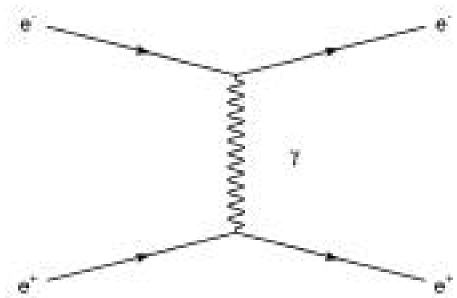
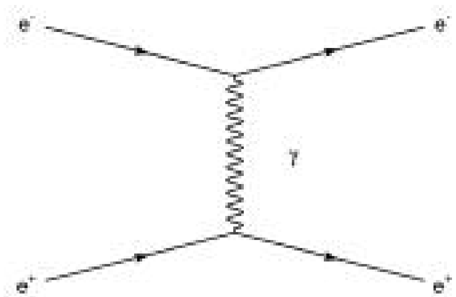


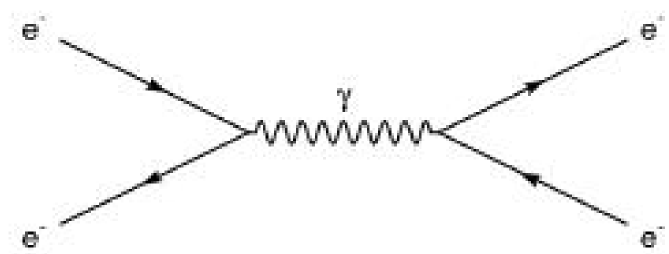
Note that an electron going backward in time is equivalent to an electron going forward in time.

M =



exchange

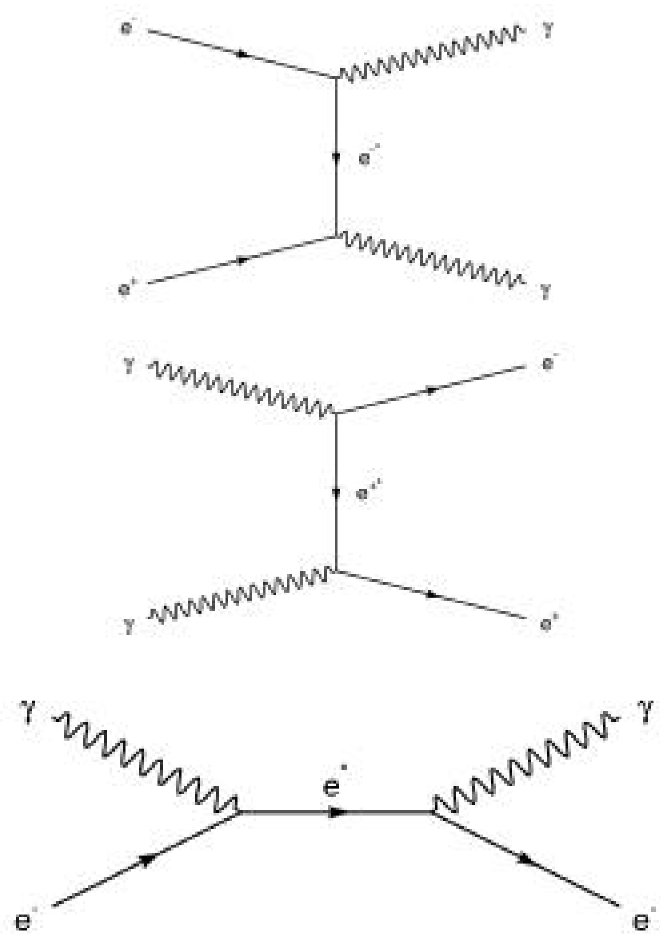
+



annihilation

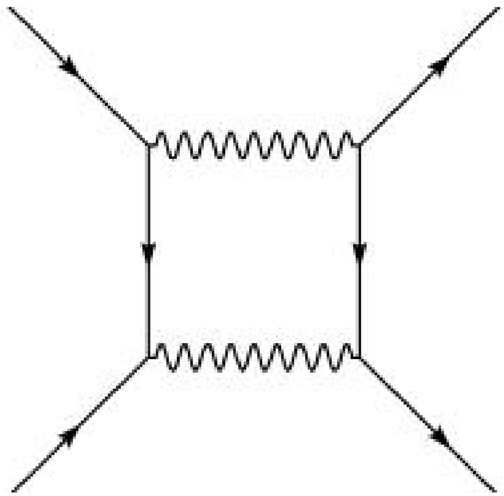
Transition amplitudes (matrix elements) must be summed over indistinguishable initial and final states.

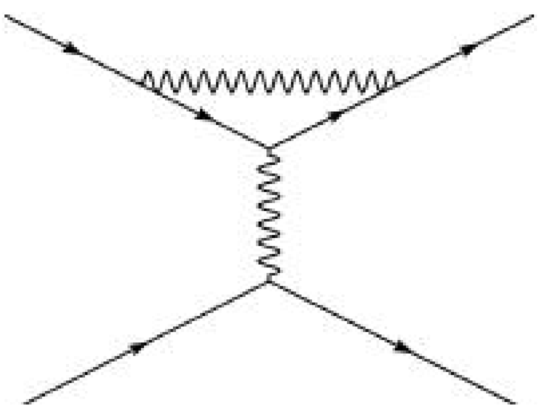
More First Order QED



- Essentially the same Feynman diagram describes the amplitudes for related processes, as indicated by these three examples.
- The first amplitude describes electron positron annihilation producing two photons.
- The second amplitude is the exact inverse, two photon production of an electron positron pair.
- The third amplitude represents in the lowest order amplitude for Compton scattering in which a photon scatters from and electron producing a photon and an electron in the final state.

Higher Order Contributions



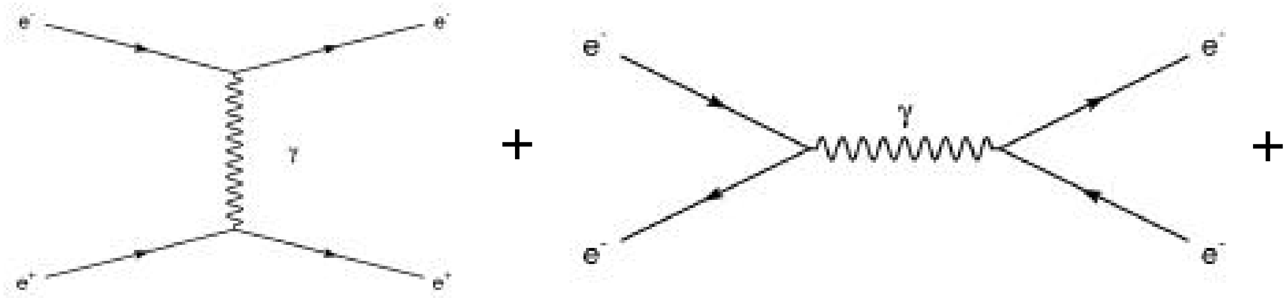


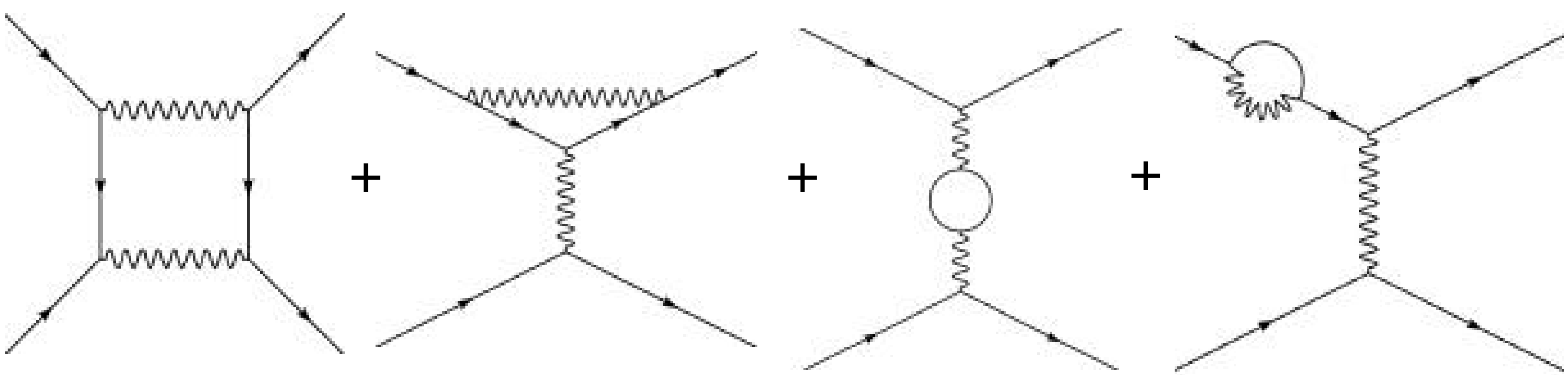
Just as we have second order perturbation theory in non-relativistic quantum mechanics, we have second order perturbation theory in quantum field theories.

These matrix elements will be smaller than the first order QED matrix elements for the same process (same incident and final particles) because each vertex has a coupling strength $e = \sqrt{\alpha}$.

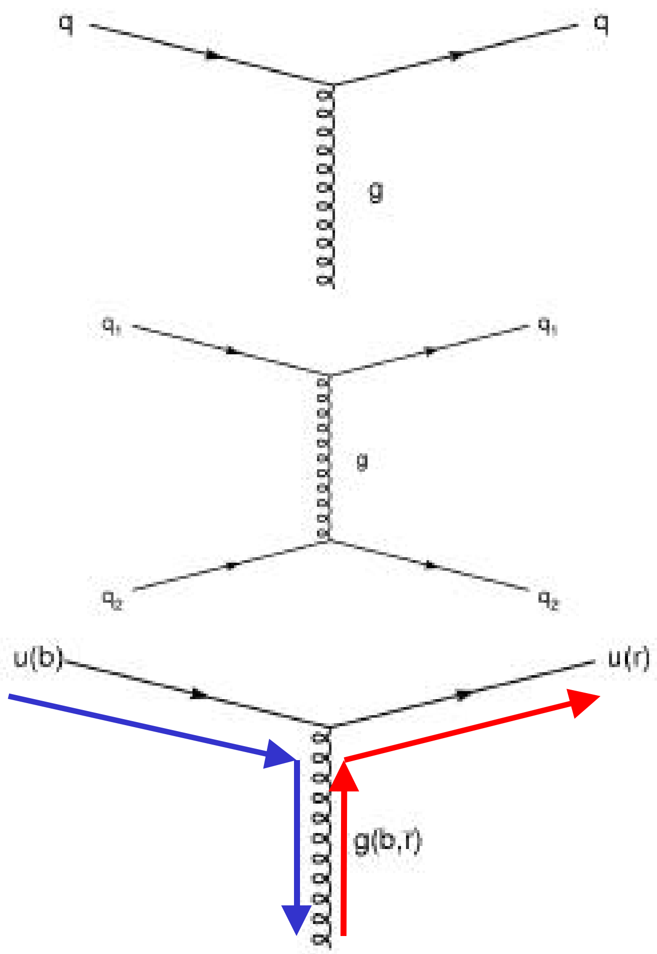
Putting it Together

M =



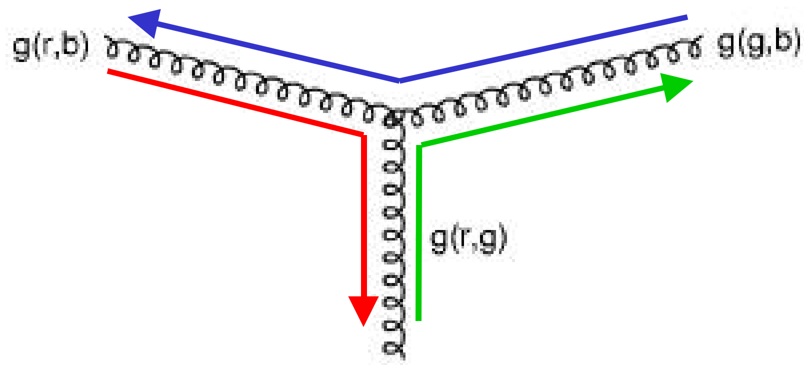


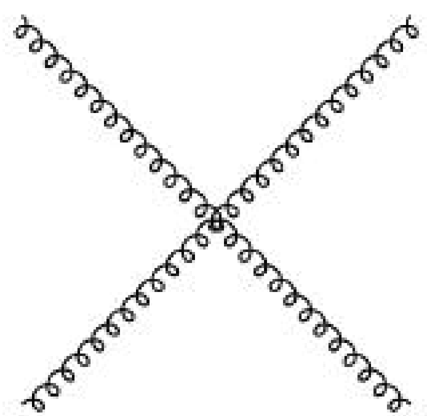
Quantum Chromodynamics (QCD) [Strong Interactions]



- **The Feynman diagrams for strong interactions look very much like those for QED.**
- **In place of photons, the quanta of the strong field are called gluons.**
- **The coupling strength at each vertex depends on the momentum transfer (as is true in QED, but at a much reduced level).**
- **Strong charge (whimsically called color) comes in three varieties, often called blue, red, and green.**
- **Gluons carry strong charge. Each gluon carries a color and an anti-color.**

More QCD





- Because gluons carry color charge, there are three-gluon and four-gluon vertices as well as quark-quark-gluon vertices.

- QED lacks similar three-or four-photon vertices because the photon carries no electromagnetic charge.

$$\alpha_S \approx 0.1 - 1$$

$$\alpha_{EM} \approx 1/137$$

Vacuum Polarization -- in QED

- **Even in QED, the coupling strength is NOT a coupling constant.**

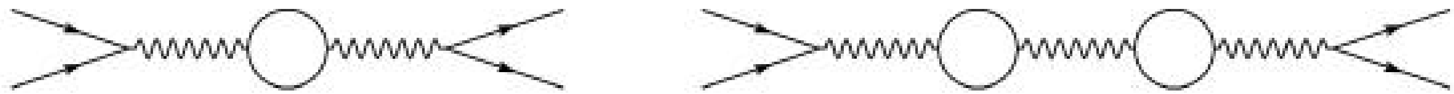
- **The effective coupling strength depends on the effective dielectric constant of the vacuum:**

$$q_{eff} = q / \varepsilon$$

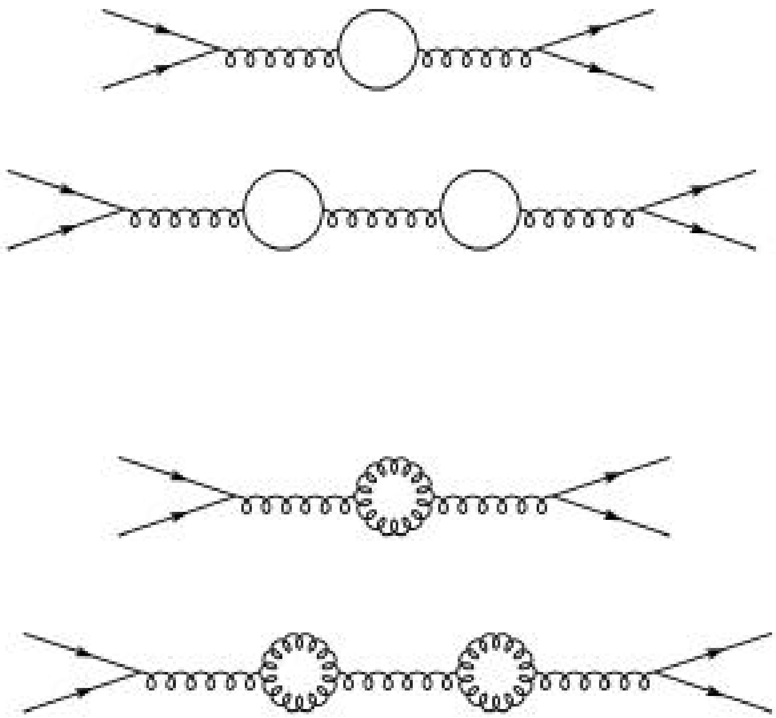
where ε is the effective dielectric constant.

- **Long distance ⇔ low q^2 ⇔ more dielectric (vacuum polarization) ⇔ lower effective charge. (Simply an assertion here.)**

- **Short distance ⇔ higher effective charge.**



Vacuum Polarization -- in QCD

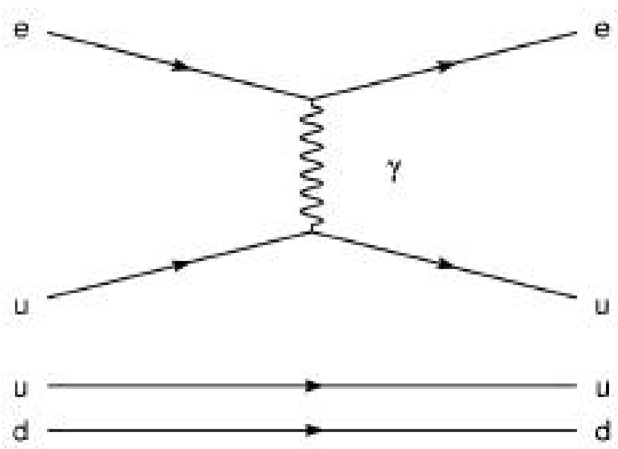


- For every vacuum polarization Feynman diagram in QED, there is a corresponding vacuum polarization in QCD.
- In addition, there are vacuum polarization diagrams in QCD which arise from gluon loops.
- The quark loops lead to screening, as do the fermion loops in QED. The gluon loops lead to anti-screening.
- The net result is that the strong coupling strength is large at long distance and small at short distance.

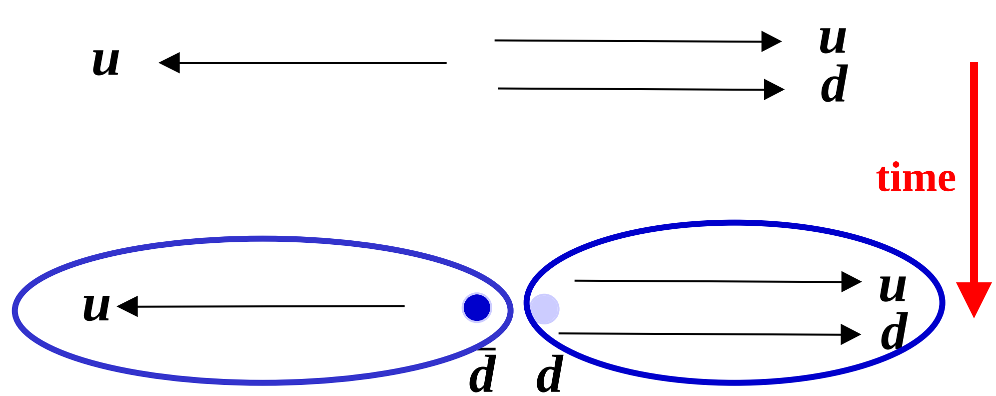
Confinement in QCD

- $\alpha_S(Q^2)$ increases at small Q^2 confinement.
- As an example, $q\bar{q} \Leftrightarrow u\bar{d}$ is a color-singlet, $c\bar{c}$.
- Less obviously, $qqq = uud$ is also a color-singlet, rgb.

short distance

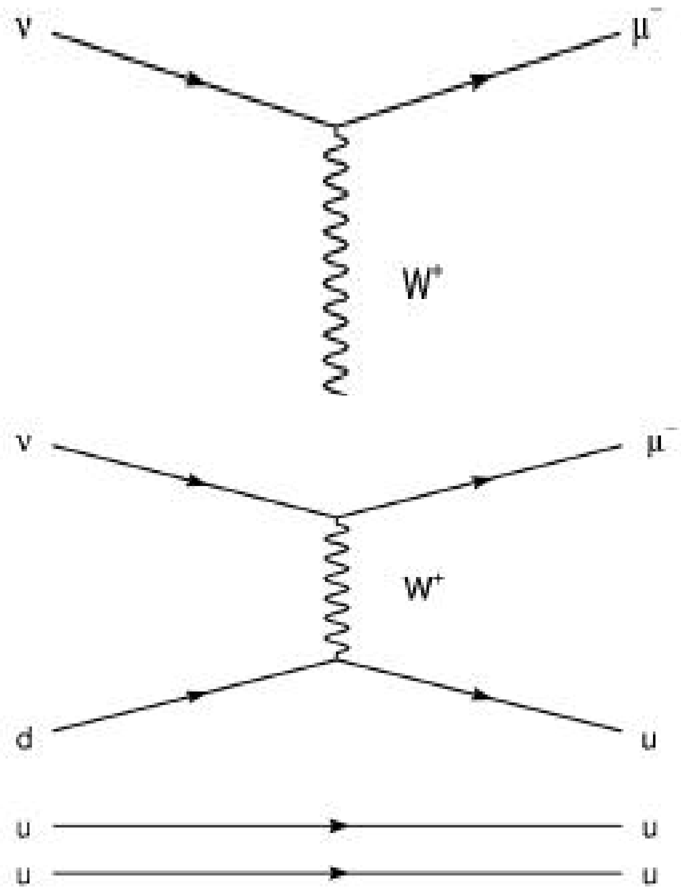


hadronization



$\pi^+ = u\bar{d}$ $\quad$ $n = udd$

Weak Charged Current Interactions
A First Introduction



- **The quantum of the weak charged-current interaction is electrically charged. Hence, the flavor of the fermion must change.**

- **As a first approximation, the families of flavors are distinct:**

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix} \quad \begin{matrix} Q = -1 \\ Q = 0 \end{matrix}$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{matrix} Q = +2/3 \\ Q = -1/3 \end{matrix}$$

- **The coupling strength at each vertex is the same.**