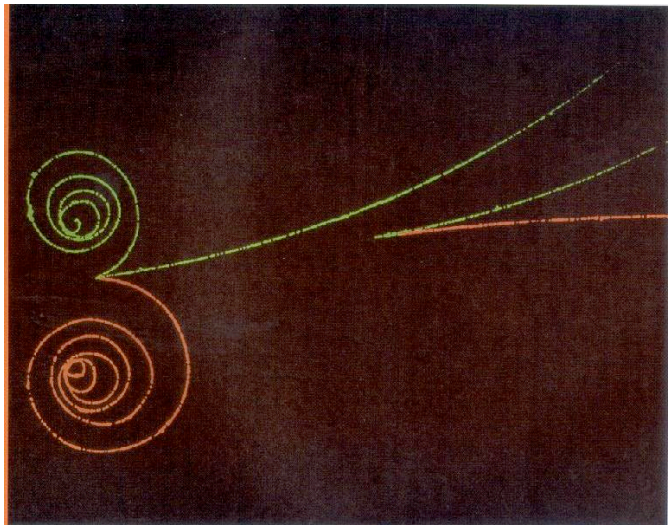
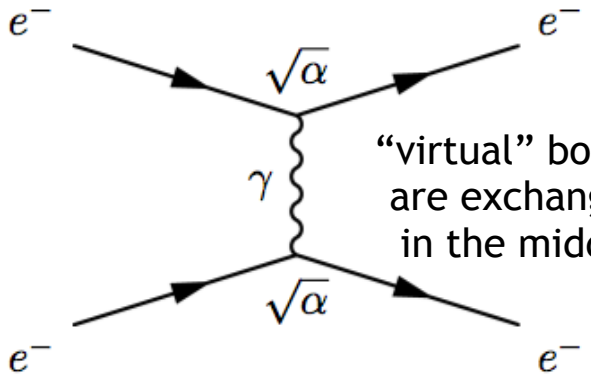
Particle Physics

Dr Victoria Martin, Spring Semester 2012
Lecture 3: QCD & Weak Force
Getting Quantitative



★Feynman Diagrams
★QCD and the Weak Force
★Scattering & Decays
★Fermi's Golden Rule
★Phase Space

Drawing Feynman Diagrams



Initial state particles on the left

Final state particles on the right

"virtual" bosons are exchanged in the middle

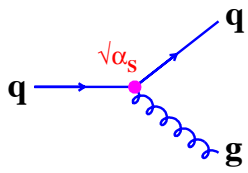
Times flows from left to right

Each interaction vertex has a coupling constant

fermions | antifermions | photons, W, Z bosons | gluons | H bosons

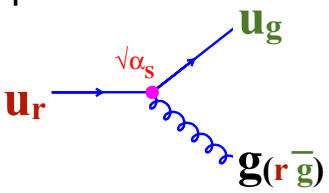
Quantum Chromodynamics (QCD)

- QCD is the quantum description of the strong force.
- Basic vertex similar to QED, except gluons couple to colour charge.



➡ Leptons to not interact due to the strong force as leptons have no colour charge.

- Gluons exchange the colour charge between the quarks.

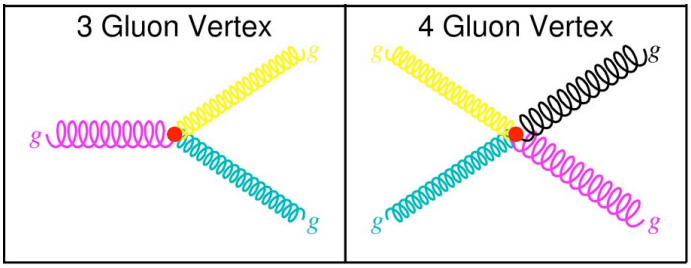


➡ Gluons themselves are bi-coloured. Suggests 3x3=9 different gluons, but actually only 8 (symmetry considerations).

➡ As gluons are colour charged they also interact with themselves due to strong force!

QCD continued

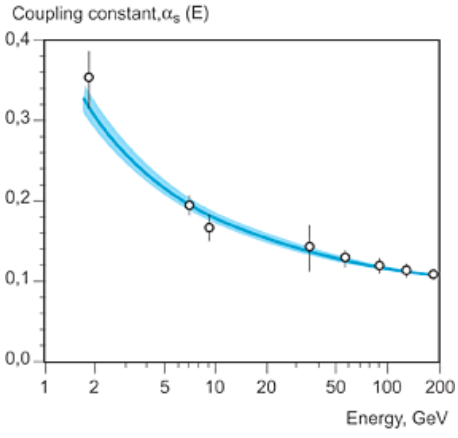
- Gluon-self interactions: the theory of the strong force imply two possible gluon self interaction vertices:



- No similar diagrams in QED

- The QCD coupling constant is $\alpha_S \sim 0.1 - 1$, much larger than QED $\alpha = 1/137$.

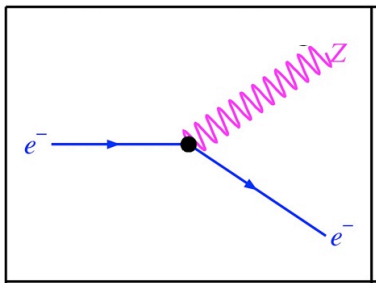
- (Due to gluon self interactions) α_S gets larger as energy gets smaller.
  - At small energy $\alpha_S \sim 1$
  - cannot use perturbation theory any more.
  - Cannot say diagrams with many gluon vertices are less likely than those with less.



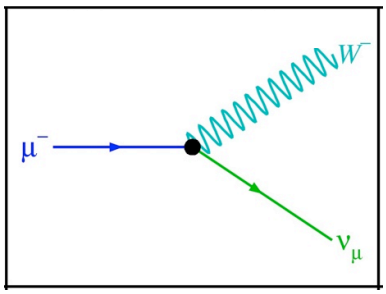
Weak Force

- The weak force involves the change of the massive W and Z bosons.

- Any fermion (quark, lepton) may emit or absorb a Z boson.
  - ➡ That fermion will remain the same flavour.
  - ➡ Very similar to QED, but neutrinos can interact with a Z boson too.



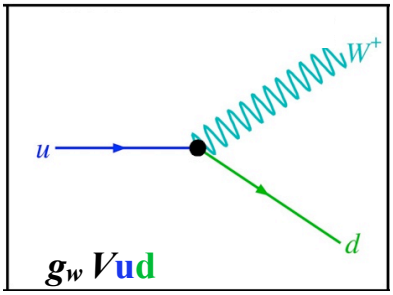
- Any fermion (quark, lepton) may emit or absorb a W boson.
- Coupling constant is at the vertex is g_w
  - ➡ To conserve electric charge that fermion **must** change flavour!
  - ➡ To conserve lepton number $e \leftrightarrow \nu_e$, $\mu \leftrightarrow \nu_\mu$, $\tau \leftrightarrow \nu_\tau$



Quark Interactions with $W^{\pm}$ bosons

- A quark may emit or absorb a W boson.
  - ➡ This will change the flavour of the quark.
  - ➡ Any up-type-quark ↔ any down-type-quark:

    $u_i \leftrightarrow d_j$



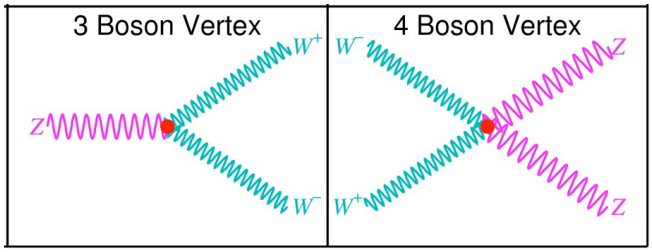
- *e.g.* $u \rightarrow Wd$, $u \rightarrow Ws$, $u \rightarrow Wb$ are all possible
  - ➡ Experimental measurements imply these possibilities not equally likely.
  - ➡ Write a modified coupling at the vertex $g_w V_{u_i d_j}$.
  - ➡ The constants $V_{u_i d_j} = \{V_{ud}, V_{us}, V_{ub}, V_{cd}, V_{cs}, V_{cb}, V_{td}, V_{ts}, V_{tb}\}$ are measured experimentally.

V_{ud}=0.974	V_{us}=0.227	V_{ub}=0.004
V_{cd}=0.230	V_{cs}=0.972	V_{cb}=0.042
V_{td}=0.008	V_{ts}=0.041	V_{tb}=0.999

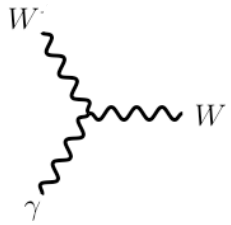
This is the CKM matrix (more in a future lecture)

W and Z self-interactions

- W and Z bosons can interact with each other.
- Allow vertices are:



- As the W boson is charged it also interacts through the electromagnetic force:



- For completeness, two more vertices exist
  - ➡ Both small in magnitude we won't have to worry about them