The Standard Model

MATTER

Pointlike spin 1/2 fermions

	LEPTONS	chg	mass	QUARKS	chg	mass
1st family	e^-	–1	0.5	d	–1/3	0.3
	ν_e	0	~ 0	u	+2/3	0.3
2nd family	μ^-	–1	106	s	–1/3	0.5
	ν_μ	0	~ 0	c	+2/3	1.5
3rd family	τ^-	–1	1777	b	–1/3	4.5
	ν_τ	0	~ 0	t	+2/3	175
			(MeV)			(GeV)

FORCES

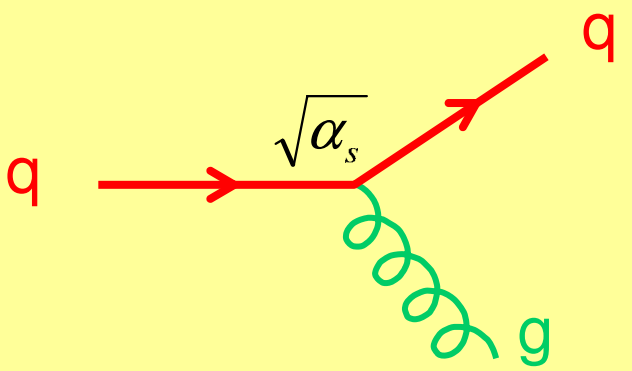
Mediated by gauge bosons

Force	Boson(s)	J^P	Mass (GeV)
E-M	photon	1^-	0
weak	$W^\pm$, Z^0	1^-	80 – 90
strong	8 gluons	1^-	0
gravity	graviton	2^+	0

plus: spin 0 Higgs boson generating masses

(114 GeV ???)

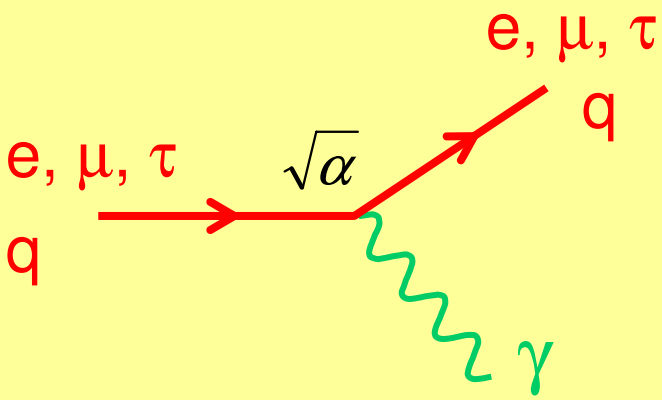
Standard Model Vertices



Strong interaction

quarks + antiquarks

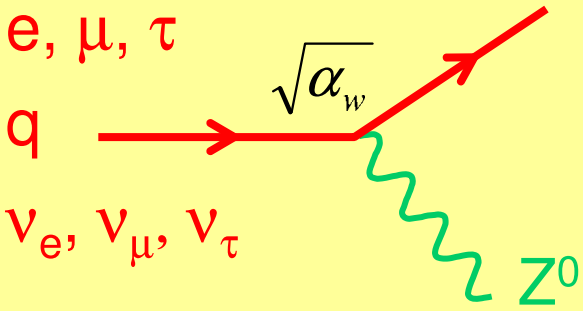
no change of flavour



EM interaction

any charged particle

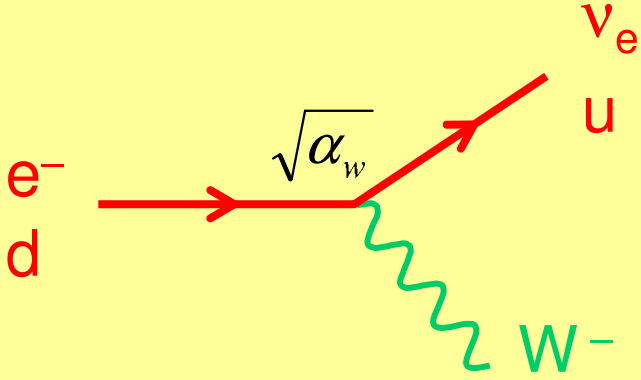
no change of flavour



Weak neutral current

all quarks + leptons

no change of flavour



Weak charged current

all quarks + leptons

flavour must change

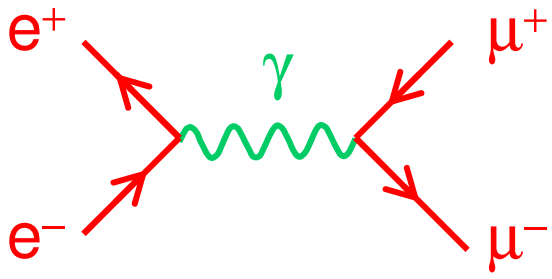
Overview of first few lectures

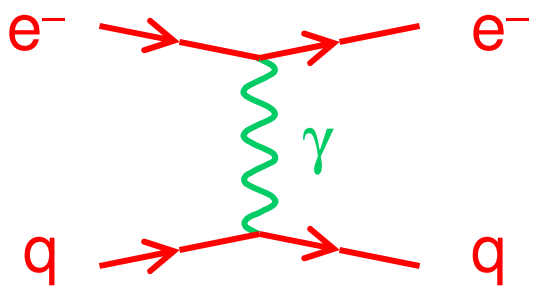
- Aiming towards proper calculation of decay and scattering processes

focusing on

$e^+e^- \rightarrow \mu^+\mu^-$

$e^-q \rightarrow e^-q$





➡ probe structure of proton

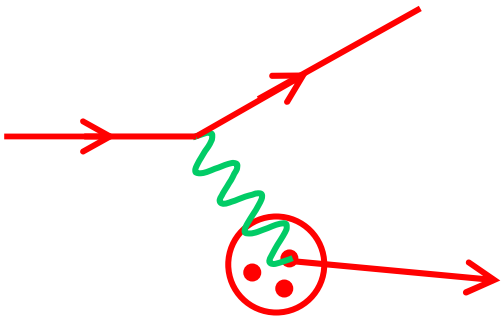
- For this, need
  - relativistic treatment of spin half particles (Dirac equation)
  - relativistic calculation of decay rates and cross sections

$$\sigma \propto \frac{|M|^2}{\text{flux}} \times (\text{phase space})$$

  - calculation of matrix elements (Feynman rules)

Overview of remaining lectures

- Deep-inelastic scattering
  - evidence for spin 1/2, fractionally charged quarks, and gluons



probe ~ 10^{-18} m

- Strong interactions
  - hadrons
  - symmetries: SU(2) and SU(3)
- Weak interactions
  - parity violation
  - CP violation

(matter - antimatter asymmetry)

- Electroweak unification
  - gauge theories
  - the Higgs boson
- Beyond the Standard Model
  - neutrino oscillations

(dark matter)

  - GUTs, proton decay, SUSY

4-vectors

- 4-momentum :

$$p^{\mu} = (E, \mathbf{p}) = (E, p_x, p_y, p_z)$$
$$p_{\mu} = (E, -\mathbf{p}) = (E, -p_x, -p_y, -p_z)$$

- Scalar product : (Lorentz invariant)

$$p_1 . p_2 = p_1^{\mu} p_{2\mu} = p_{1\mu} p_2^{\mu} = E_1 E_2 - \mathbf{p_1} . \mathbf{p_2}$$
$$p^2 = E^2 - \mathbf{p}^2 = m^2$$
$$(p_1 + p_2)^2 = p_1^2 + p_2^2 + 2 p_1 . p_2 = m_1^2 + m_2^2 + 2 p_1 . p_2$$

- Derivative and current 4-vectors :

$$\partial^{\mu} = \left(\frac{\partial}{\partial t}, -\nabla \right) = \left(\frac{\partial}{\partial t}, -\frac{\partial}{\partial x}, -\frac{\partial}{\partial y}, -\frac{\partial}{\partial z} \right) \qquad j^{\mu} = (\rho, \mathbf{j})$$

$$\partial_{\mu} \partial^{\mu} = \frac{\partial^2}{\partial t^2} - \nabla^2 \qquad \partial_{\mu} j^{\mu} = \frac{\partial \rho}{\partial t} + \nabla . \mathbf{j}$$

- Natural units : $\hbar = c = \varepsilon_0 = 1$

$$\hbar c = 0.197 \, \text{GeV.fm}$$
$$\hbar = 6.582 \times 10^{-25} \, \text{GeV.s}$$