

## Outline

- Relativistic Kinematics
  - ▶ (4-momentum)<sup>2</sup> invariance, invariant mass
  - ▶ Hypothesis testing, production thresholds
  - ▶ Cross-sections, flux and luminosity, accelerators
  - ▶ Particle lifetime, decay length, width
- Classification of particles
  - ▶ Fermions and bosons
  - ▶ Leptons, hadrons, quarks
  - ▶ Mesons, baryons
- Quark Model
  - ▶ Meson and baryon multiplets
  - ▶ Isospin, strangeness, c, b, t quarks
- Particle Interactions
  - ▶ Colour charge, QCD, gluons, fragmentation, running couplings
  - ▶ Strong and weak decays, conservation rules
  - ▶ Virtual particles and range of forces
  - ▶ Parity, charge conjugation, CP
  - ▶ Weak decays of quarks
  - ▶ Charmonium and upsilon systems
- Electroweak Interactions
  - ▶ Charged and neutral currents
  - ▶ W, Z, LEP experiments
  - ▶ Higgs and the future
- LHC Experiments
- Future - introduction to accelerator physics

Today

• Lecture 19 (4 slides/page) Electroweak interaction

Previous lecture

• Lecture 18 (4 slides/page) - Parity violation in weak interaction, helicity  
 ◦ Williams, pp. 305-310, see also Lecture 17 textbook references.  
 ◦ Halzen and Martin, p. 254  
 ◦ C.S. Wu, E. Ambler, R.W. Hayward, D.D. Hoppes, R.P. Hudson, "Experimental Test of Parity Conservation in Beta Decay", *Phys. Rev.* 105. 1413 (1957).

## Helicity for massive fermions

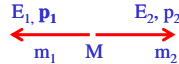
- W couples preferentially to LH fermions (RH anti-fermions)

$$\frac{W - RH \text{ fermion}}{W - LH \text{ fermion}} = \left( \frac{m_{\text{fermion}}}{E_{\text{fermion}}} \right)^2 = \frac{1}{\gamma_{\text{fermion}}^2}$$

- "Wrong" helicity states strongly suppressed
- Suppression greater for lighter fermions (of a given energy)
- Example: charged pion decay

## Calculation of helicity suppression

- $\pi^+$  decays to particles 1, 2
- $E_1 + E_2 = M$
- $|p_1| = |p_2|$
- Use  $E^2 = p^2 + m^2$ , solve for  $E_1$ , find
  - ▶  $E_1 = (M^2 + m_1^2 - m_2^2) / 2M$
- Consider particle 1 as either  $\mu^+$  or  $e^+$ , particle 2 as  $\nu_{\mu}$  or  $\nu_e$
- Masses (MeV/c<sup>2</sup>):  $\pi^+ = 139.6$ ,  $\mu^+ = 105.7$ ,  $e^+ = 0.511$



Particle	Energy (MeV)	Lorentz $\gamma$
$\mu$	109.8	1.039
$e$	69.8	139.6

- Relative suppression =  $(\gamma_{\mu} / \gamma_e)^2 = 18000$  (expt.  $\sim 10^4$ )

## Weak Interaction

- Universal: acts on all quarks and all leptons
- Characterised by long lifetimes and small cross-sections
- At low energies, WI overwhelmed by SI and EM
  - ▶ Can be observed when SI and EM forbidden, or by very precise measurements
- Often involve neutrinos, e.g.  $n \rightarrow pe^-\bar{\nu}_e$
- Charged current WI change quark flavour
  - ▶ Observed change in hadron flavour  $D^+ \rightarrow \bar{K}^0 \pi^+$   
 $(c\bar{d}) \rightarrow (s\bar{d})(u\bar{d})$
- Can violate parity and charge conjugation invariance
  - ▶ At much lower level, also violates T and the combined symmetry of CP