

# 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

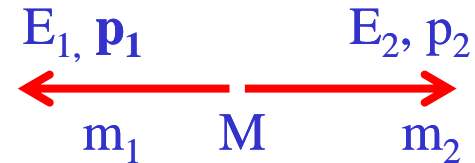
- $W$  couples preferentially to LH fermions (RH anti-fermions)

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

- "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  $\nu_\mu, \nu_e$

- Masses ( $\text{MeV}/c^2$ ) :  $\pi^+ = 139.6, \mu^+ = 105.7, e^+ = 0.511$

Particle 1	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