Particle Physics – Summary

Kinematics

$E^2 = p^2c^2 + m^2c^4$ units GeV, GeV/c, GeV/c^2

$E^2 - p^2c^2$ for any system of particles is invariant.

Also see introductory notes and homeworks.

Fermi's Golden Rule

$$\text{Transition rate} = \frac{2\pi}{\hbar}\left|M_{\text{fi}}\right|^2 D_{\text{f}}$$

$$M_{\text{fi}} = \int_{\text{space}} \psi^* V(\underline{r})\psi \, \text{d}\underline{r} = \int e^{i\underline{q}.\underline{r}/\hbar} V(\underline{r}) \, \text{d}\underline{r}$$

Fourier Transform of scattering potential.

$\underline{q}$ = (3-) momentum transfer.

Application:

- FT of charge distribution gives Form Factor (example of convolution theorem)

Particles

Bosons – integer spin, Bose-Einstein statistics, symmetric multi-particle wave function.

Exchange particles — mesons ($q\bar{q}$)

γ, $W^{\pm}$, Z^0, g — π, K, ω, ρ, …

Fermions – $\frac{1}{2}$ integer spin, Fermi-Dirac statistics, antisymmetric multi-particle wavefunction.

Fundamental — baryons (qqq)

leptons — quarks — p, n, Δ, Ω, Ξ, …

0 ν_e ν_μ ν_τ — $^2/_3$ u c t

–1 e μ τ — $-^1/_3$ d s b

3 lepton nos. conserved — *baryon number conserved*

Interactions and Fields

strong — electromagnetic — weak — (gravitation)

exchange forces – boson exchanged, mass m, coupling g

$\Rightarrow$ Effective potential $\varphi = g^2 \dfrac{e^{-r/R}}{r}$ $\quad R = \dfrac{\hbar}{mc}$

amplitude $\propto \dfrac{g^2}{q^2 + m^2c^2}$ $\quad \dfrac{1}{q^2 + m^2}$ known as propagator.

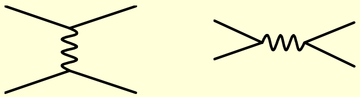
Invariance Principles and Conservation Laws

e.g. isotropy in space $\rightarrow$ momentum conservation etc.

some quantities, e.g. P, C not conserved in weak int^n.

Feynman diagrams

relationship between scattering and annihilation



multiple exchanges, loops, …

appear to predict infinite cross sections etc, until we realise we must not assume the "bare" mass & charge are the same as the observed values.

Any observation includes the result of loops.

Express predictions in terms of observable quantities $\rightarrow$ finite results.

Accurately tested (for QED) : g – 2 experiment

Electromagnetic – couples to charged particles

- exchange of photons (massless).

Strong interaction – couples "coloured" objects

– only the quarks (& hadrons)

– exchange of coloured gluons.

$\exists$ 3 colours (r, g, b). All hadrons are antisymmetric in colour (colour singlets or "white").

$\Rightarrow$ only $\overset{r}{q}\,\overset{g}{q}\,\overset{b}{q}$ or $q\,\bar{q}$ allowed.

Gluons interact with each other.

Strength of strong interaction (α_S):

large at long distance or low momentum transfer,

decreasing at small distance or large mom. trans.

When quarks are produced in an interaction, they "dress up" into hadrons (in jets).

Type or flavour of quarks are conserved. Distinguished by isospin (u,d), strangeness, charm, etc.

Weak interaction – couples all quarks & leptons

– exchange of massive $W^{\pm}$, Z^0.

Coupling constant $\approx$ that of EM (unification).

Large mass of W, Z make force weak at "low" energies.

Charges current ($W^{\pm}$ exchange) "mixes" quarks

– so violates isospin, strangeness, … conservation.

– CKM matrix etc. (but no mixing of leptons).

Weak int^n. also violates C & P, as ν only exists with LH polarisation ($\bar{\nu}$ exists only with RH polarisation.

CP is an approximate symmetry of weak interaction.

The Standard Model of Particle Physics

Fermions

Leptons		Quarks	
e	ν_e	d	u
μ	ν_μ	s	c
τ	ν_τ	b	t

Bosons

Bosons
γ
$W^{\pm}$, Z^0
g

H^0

Evidence for (only) 3 generations – from Z^0 decays.

Evidence for quark colour and charge – from $e^+ e^-$ annihilation to hadrons.

Evidence for point-like quarks – from deep inelastic scattering (scaling).

Evidence for quark confinement – from deep inelastic scattering & jets.

Other key points:

quark antisymmetry in baryons (decuplet & octet)

virtual particles (space-like and time-like virtual photons)