Lecture 3

Master Particle Physics 1

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Lectures PP1

L0 : Introduction

L1 : Particles and Fields (historical overview)
L2 : Wave Equations and Antiparticles
L3 : The Electromagnetic Field
L4 : Perturbation Theory and Fermi's Golden Rule
L5 : Electromagnetic Scattering of Spinless Particles

QED of Spinless Particles: Scattering Theory and Cross Sections

L6 : The Dirac Equation
L7 : Solutions of the Dirac Equation
L8 : Spin 1/2 Electrodynamics

QED for Fundamental Fermions

L9 : The Weak Interaction
(Fermi 4-point scattering: an analogy with QED)
L10: Local Gauge Invariance
(the role of symmetries in interactions)
L11: Electroweak Theory
L12: The Process: $e^+e^- \to \gamma, Z \to \mu^+\mu^-$

The Standard Model for massless particles $SU(2)_L \times U(1)_Y$

Standard Model for particles

Fermions (Spin 1/2 particles) :The basic constituents of matter

Quarks:

$$\begin{pmatrix} u, u, u \\ d, d, d \end{pmatrix} \begin{pmatrix} c, c, c \\ s, s, s \end{pmatrix} \begin{pmatrix} t, t, t \\ b, b, b \end{pmatrix}$$

Quarks only occur in colour neutral objects: "Hadrons"
Baryons: qqq
Mesons: $q\bar{q}$
⇒ Hadron particles occur in multiplets

Leptons:

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

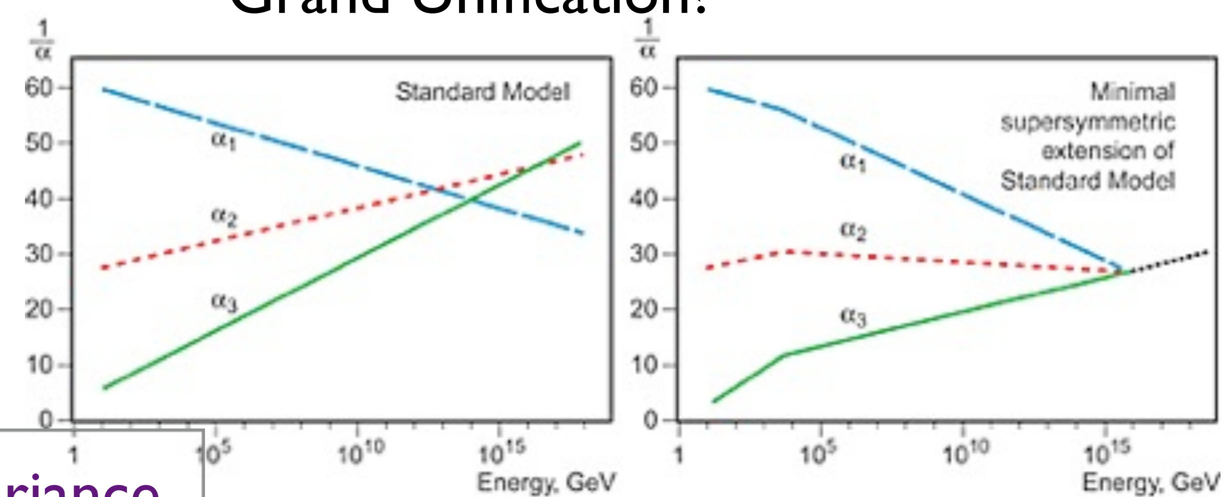
Only 3 generations of fundamental particles are known

Vector Bosons (Spin 1 particles). force carriers

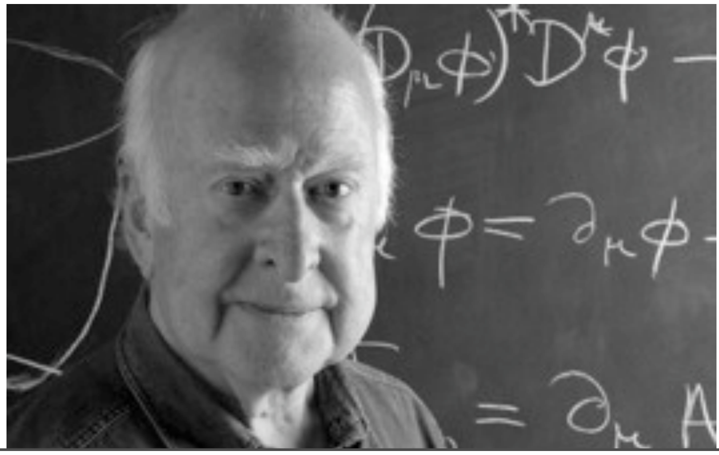
Strong interaction	8 gluons
Weak interaction	W^+ W^- Z^0
Electromagnetic interaction	γ
Gravity	g

⇒Forces originate from principle of local gauge invariance

Grand Unification?



Scalar Boson (Spin=0 particle).
Generates fermion masses via the Higgs mechanism



Matter Waves for Particles without Spin

	Non relativistic:	Relativistic:
Kinematics:	$E = \frac{\vec{p}^2}{2m}$	$E^2 = \vec{p}^2 + m^2$
Quantum Mechanics:	$E \to \frac{\partial}{\partial t} \quad \text{and} \quad \vec{p} \to -i\vec{\nabla}$	$E \to i\frac{\partial}{\partial t} \quad \text{and} \quad \vec{p} \to -i\vec{\nabla}$
Wave Equation:	$i\frac{\partial}{\partial t}\psi = \frac{-1}{2m}\nabla^2\psi$	$-\frac{\partial^2}{\partial t^2}\phi = -\nabla^2\phi + m^2\phi$

Continuity Equation: $\vec{\nabla}\cdot\vec{j} = -\frac{\partial\rho}{\partial t} \quad \text{or} \quad \partial_\mu j^\mu = 0$

Probability density and current:

$$\begin{aligned} \rho &= \psi^*\psi = |N|^2 \\ \vec{j} &= -\frac{i}{2m}\left(\psi^*\vec{\nabla}\psi - \psi\vec{\nabla}\psi^*\right)\frac{|N|^2}{m}\vec{p} \end{aligned}$$

$$\begin{aligned} \rho &= i\left(\phi^*\frac{\partial\phi}{\partial t} - \phi\frac{\partial\phi^*}{\partial t}\right) = 2|N|^2E \\ \vec{j} &= -i\left(\phi^*\vec{\nabla}\phi - \phi\vec{\nabla}\phi^*\right) = 2|N|^2\vec{p} \end{aligned}$$

Negative Energy solutions: $j^\mu(+e) = 2e|N|^2\ (E,\vec{p}) = -2e|N|^2\ (-E,-\vec{p})$

The negative energy solution of a particle traveling backwards in time =
the positive energy solution of the antiparticle traveling forwards in time