Lecture 1

Tuesday, January 18, 2022    10:01 AM

Physics 613 - Intro to the Standard Model
no prior QFT required
will be heuristic often

Lectures: Tues & Fri 10:20 - 11:40

Jan: Zoom
Feb onwards: NHETC seminar room (if pandemic permits)

Grades: ~10 HWs (every 1.5 weeks or so)
attendance, participation

Textbook: Aitchison & Hey and 3rd editions
**Standard Model**

Goal is to understand:

\[ L = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\psi} D^\mu \psi + \bar{\chi} Y_j \chi_j \phi + 12|\phi|^2 - V(\phi) \]

Lagrangian of SM.
SM is the most successful theory of Nature ever written down:
- tested to unprecedented precision and scales
- describes all known fundamental matter & interactions
  in a single, unified framework (based on QFT - QM + relativity)
  - EXCEPT
    - Dark matter
    - Gravity
    - Neutrino masses
    - Matter antimatter asymmetry / baryogenesis
  - Cosmological constant problem
  - Hierarchy problem
    - Why gravity << forces
  - Strong CP problem
    - 3 generations of quarks & leptons
Historical Introduction

1860 ~ 1897  \rightarrow  2012
Maxwell  \quad Thomson  \quad electrons  \quad \quad \quad Higgs

\sim 150 \text{ years in the making.}

Rutherford, Geiger, Marsden

"fixed target"

Like shooting a gun at piece of paper & having bullet bounce back"

Importance of scattering experiments to particle physics

Atoms were electrically neutral
Electron charge - what balances it?

Plan a daily walk 
\nu \sim 10^{-10} \text{ m}

nuclear model \quad r \sim 10^{-15} \text{ m}

Size of N \leq 35 fm
could also: $m_e \sim 0.5 \text{ MeV}$

deduce: $m_p \sim 1 \text{ GeV} = 1000 \text{ MeV}$

Nuclear model: $\text{Atom} \rightarrow \text{QM}$

Puzzles: what holds protons in nucleus together? what overcomes electric repulsion?

Puzzles: what mass nucleus $\sim 2 \times \text{(mass of # of protons)}$

1932 Chadwick - discovery of neutron.

Bombarded Be targets with high energy alpha particles -> highly penetrating radiation

-neutral particle with mass $\sim m_p$.

$\hbar = c = 1 \Rightarrow \text{length} \sim \text{time} \sim \text{(mass)}^{-1}$
What holds nucleons together?

→ New force! "Strong nuclear force" → First theory 1935 Yukawa

\[ g \sim 1 \text{ fm} \sim (100 \text{ MeV})^{-1} \]

Energy scale associated to strong force.

SLAC 1950s-1960s
Hoffstadter et al.

Repeated Rutherford but at very high energy (at the time) electrons instead of \( \alpha \) particles.

\( m_{\pi} \sim 100 \text{ MeV} \)
Fund scattering inconsistent w/ point-like nucleus.

50s-60s golden era for nuclear physics

nuclear spectroscopy

excited $\Xi \rightarrow \Xi$

\[ e \rightarrow \Xi \rightarrow \Xi \rightarrow \Delta \rightarrow \pi^+ + \pi^- \]

"baryons" \[ m \sim 100 MeV \]

\[ m_{\Xi} \sim 1 / 10 m_p \]

points to nucleons having internal structure being composite \( \rightarrow \) not fundamental!

"baryons + mesons \( \rightarrow \) hadrons"
1964 Gellman Zweig

baryons: 3 quarks

mesons: 2 quarks

\[ \begin{align*}
\pi & : \ u \bar{u} \\
\pi^0 & : \ u \bar{u} \\
\pi^+ & : \ d \bar{u} \\
\pi^- & : \ d \bar{u} \\
\end{align*} \]

\[ \begin{align*}
\text{u} : & \ u \ u \ d \\
\text{d} : & \ u \ d \ d \\
\text{p} : & \ u \ u \ d \\
\text{n} : & \ u \ d \ d \\
\Delta : & \ u \ u \ u \ d \\
\text{d} & \rightarrow \ u \ d \ u \ d \ u \ d \ d \\
The fractionally charged pions explained a lot of observations at time, but people were skeptical...

Where are the quarks? No evidence for "bar quarks"

1968 SLAC Deep inelastic scattering

\[ e \rightarrow p \] scatter proton (inclusive) \rightarrow evidence for pt like constituents (proton model)
1974 "November Revolution"

Discovery of $J/\psi$ pair (resonance) $\rightarrow$ Richter, SLAC

predicted by quark model Glashow, Iliopoulos, Maiani

new quark "charm" $m_c \sim 1.26$ GeV

$\bar{c}c$ charmonium resonance

agreed with $J/\psi$

finally convinced everyone quarks were real.
Nowadays we “see” bare quarks & gluons at LHC

radiate via strong force

→ one of energetic particles “jets”

no bare quarks in nature b/c QCD confinement & hadronization