The Nuclear Physics Weekly I

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Contents

1 Week 1

1.1 Overview

The first lecture started with outlining and discussion of modalities for the program. We then moved on to introduction of various topics in nuclear physics. Topics discussed in the first lecture are listed below:

- Fundamental Forces : Gravitation, Electromagnetic, Strong and Weak Forces
- Standard Model : Quarks and Bosons (specifically gluons)
- QCD - Theoretical framework for strong nuclear force.
- Lattice QCD - A non-perturbative approach to solving a QCD Systems.
- Particle Physics : Feynman diagrams and Resonance.

1.2 Introduction

1.2.1 Strong force

Strong force was then introduced in more detail. Strong force is the force that keeps protons and neutrons together. Quarks inside them interact through this strong force with gluons acting as force carriers. Gluons play a similar role in QCD as electron play in QED but keep in mind that gluons are much more involved than photons because color - analog of charge in QCD - of quarks can change unlike charge and gluons have to interact with differently colored quarks whilst conserving color of the confined system and they also interact with themselves unlike photons.

1.2.2 QCD

Dr. Briceno then expanded a bit more on QCD. Quarks and gluons carry different "color" (*red, green, blue*) and quarks come in 6 different "flavors" : *up, down, strange, charm, top, bottom.* Note that the flavors at odd places are in one family and than on even are in one. Properties of quarks in a family remain same other than the mass which get heavier to the right. Also note that heavier quarks are much more unstable that the lighter ones and hence up, down and strange quark are most abundant.

We never find quarks independently in the wild, they are always found in confined state. These structures are called *Hadrons.* Hadrons are composite particles made up of two or more quarks. They are always color neutral. Hadron made of quark-antiquark pair (even number of quarks) are called *Mesons*. Hadrons composed of Odd number of quarks (at least 3) are called *Baryons*. Keep in mind that these confined structures don't just have the specifies number of quarks, more quark-antiquark pairs pop in and out of existence forming a sea of quarks inside the Hadrons.

While reading up more on QCD, I found that one the reason QCD was proposed as the framework for Strong force was the propoerty of *asymptotic freedom*. Asymptotic freedom is the phenomenon of weak coupling for hard (high energy) gluons and high coupling for soft (low energy) gluons. This is one of the features of QCD due to which it was proposed. It is also the reason why QCD gets really hard to solve as low energies. At low energy an effective attraction happens between particles on opposite side of fermi surface which leads to pairing instability, which then results in big changes even when the perturbation is small, making the problem non-perturbative.

1.2.3 Lattice QCD

As we just discussed above, QCD at low energy is non-perturbative! Approach towards solving QCD system at high energy - which are perturbative - don't work on low energy systems. At low energies the coupling is higher coupling constant is higher and the contribution of more complex interactions is much more than in high energy systems making the calculations much more complex. Lattic QCD gets around this by taking a non-perturbative approach to solving QCD. Quarks are represented as lattice sites and gluons as links connecting them.

There are three main questions Lattice QCD is used to answer at JLab:

1. Nuclear structure : How do nucleons come together to form low-lying nuclei?
2. Hadron Structure : How do quarks come together to form hadrons?
3. Spectroscopy : What are bound states of QCD?

1.2.4 Feynman diagram

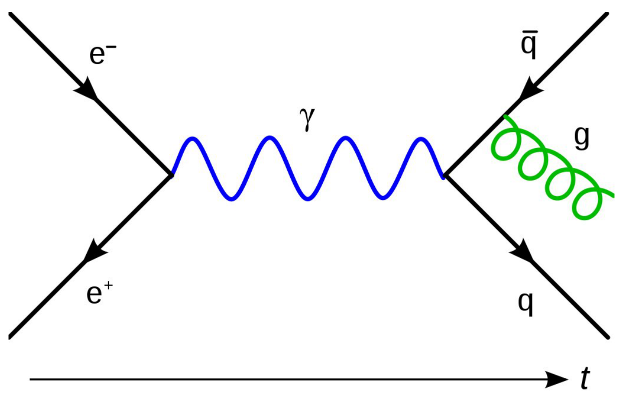

Figure 1: Feynman Diagram of Electron Positron interaction resulting in formation of quark-antiquark pair. The blue line represents photon and the green line represents gluon.

Feynman diagrams, proposed by Richard Feynman, are graphical representation of rigorous mathematical equations that govern particle interactions. One axis of the diagram (x-axis usually, unlike the above figure) represents space and the other axis time. Particles are represented as lines in the diagram and the vertices represent particle interactions.

1.2.5 QCD Spectroscopy

QCD Spectroscopy is basically probing the decaying of Hadrons. A lot of phyiscs can be extracted from this, such as, production mechanisms, prominent decay channels, structure and more! Lattice QCD is able the only tools available to us right now which generates stable states, Resonant amplitudes exactly.

1.2.6 Resonance

Resonance in particle physics is the phenomenon where probability of an interaction occurring is amplified at a particular frequency or energy. Resonance occurs because a bound state, if it can decay, will decay. When the energy of colliding particles in enough to produce rest mass, it forms and then decays quickly by strong force.

1.3 Other work

Beside the lecture, I did some reading on introductory particle physics (see Reading List) to prime myself with some (very) basic particle physics. I learnt about :

- Elementary Particles : Fermions (Leptons and Quarks) and Bosons; Hadrons (mesons and baryons)
- Particle Conservation Laws : Baryon Number, Lepton Number, Strange (not in weak)
- The Standard Model : Combines Electroweak theory and QCD.
- Drawing (basic) Feynman diagram : Complex particle interaction equations represented as diagrams with time as y-axis and position as x-axis.

1.4 Reading List

1. Particle Physics and Cosmology Ch-11 University Physics Volume 3
2. QCD Made Simple - Physics Today 53, 8, 22 (2000)
3. Particle Concepts - HyperPhysics