Final Report | REYES Mentorship program

Anish

October 23, 2021

Contents

This is the final report summarizing what I learnt throughout the REYES mentorship program. First I would like to thank Dr. Raul Briceno, Dr. Andrew Jackura and rest of the REYES staff for successfully conducting such an amazing program.

In the first week, I was introduced to fundamental aspects of nuclear physics including but not limited to Elementary Particle, Standard model, Feynman diagram and Lattice QCD. There are 17 elementary particles in the standard model, divided into fermions and bosons. The fermions or "matter particles" can be further divided into quarks and leptons. Bosons are force carrier particles. Gluon boson in particular facilitates strong force. The theoretical framework for studying strong force is QCD. One of the reasons why QCD is framework used is its propery of *asymptotic freedom*. This property also makes QCD much more computationally expensive at low energies due to high coupling for soft gluons. This is where Lattice QCD comes in, which is a non-perturbative approach to solving QCD. QCD is complex, involving really complex mathematics. This makes it really hard to visualize interactions in QCD. Feynman diagrams then come to rescue us by making it much easier to visualize particle interaction, by interpreting complex mathematical equation as diagrams that can be easily understood.

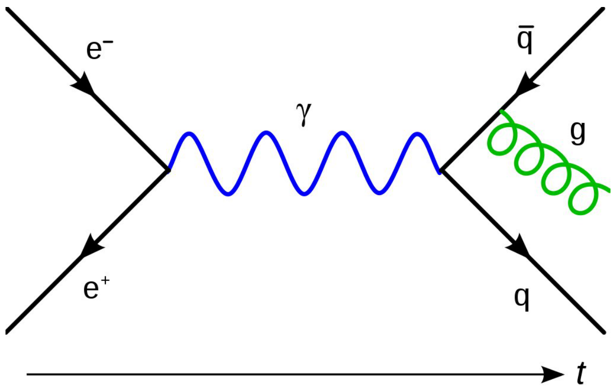

Figure 1: Feynman Diagram of Electron Positron interaction resulting in formation of quark-antiquark pair. The blue line represents photon and the green line represents gluon.

In the second week, we explored complex numbers, their properties and way to visualize them. Scattering amplitude is a complex number that establishes the probability of a scattering process and is a function of the energy in center-of-momentum frame. We then learnt about Analytic function, i.e., functions that are single-valued and differentiable everywhere at all points in some domain D over argand plane. To visualize such complex functions, say $f(z)$, we use Domain coloring, which works by coloring an argand plane W and then the color of each point of another argand plane Y is such that the color of point $z \in Y$ is the color of point $f(z) \in W$.

We looked at more of scattering theory and derived some important relations in week 3. There are some model independent features of scattering theory, such as,

- Spacetime and Internal Symmetry
- Unitarity
- Analyticity

- Crossing

  Unitarity implies a relationship between imaginary part of scattering amplitude and its modulous.

$$Im(M) = \rho|M|^2$$

Although keep in mind that this relationship is only valid when energy is $\geq 2m$ and $\leq$ first inelastic threshold. We derived polar form of scattering amplitude with help of the above relation.

$$\mathcal{M} = \frac{1}{\rho} \sin\delta e^{i\delta}$$

$\mathcal{K}$, which characterizes short range interaction between particles, was then equated to be

$$\mathcal{K}^{-1} = \rho \cot(\delta)$$

Fourth week went on with looking at particle data group's database of particle and their multiple decay modes. A particle can decay in multiple ways, given that the different conservation laws are satisfied. We also found out that lifetime of particles depend on the mechanism through which they are decaying, for example, a particle that decays via strong force will have much less lifetime compared to a particle that decays via weak force. Higher mass of a particle opens up more possible decay mechanisms due to the possibility of creation of more heavier particles. We then discussed how these hardonic resonances are produced in different facilities. Three different ways to prodcuing a resonance are show below in figure below. Note that although these resonances are created through different mechanisms, the thus produced have same properties i.e., resonances are universal.

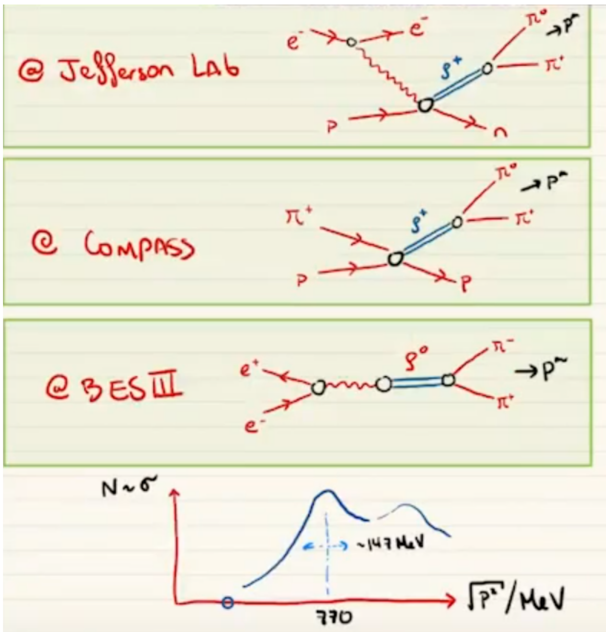

Figure 2: ρ resonance production at Jlab, COMPASS and BES III.

In last couple of weeks, we learnt how to convert feynman diagrams to mathematical equations and details about nucleon-nucleon scattering. There are certain rules for Feynman diagram in φ^4 theory for writing down a mathematical equation from the given diagrams. The rules being:

1. Every interaction point leads to a factor of $i\lambda$ where λ some real number.
2. Every external line leads to a factor of $+1$
3. Every internal line leads to a factor of $\frac{i}{p^2 - m^2 + i\epsilon}$. These internal lines are also knows as Feynman propagators.
4. Every Feynman propagator having unknown momentum leads to a factor of $\int \frac{dk_i}{(2\pi)^4}$ i.e., integrating over all possible momentum.
5. Factor of $\frac{1}{s}$ where s is the symmetric factor. Symmetric factor is the number of permutation of propagators that leaves the diagram unchanged.