Home Reading
Nucleon Resonances and Quark Structure

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November 6, 2020

Vocabulary

(words I didn't know the meaning of)

formidable — внушительный	(section 3.2)
viable — приемлемый	(section 3.2)
lattice sites — границы решетки	(section 3.2)
amass — накопить	(section 4.2)

Questions

1. What is the modern theory describing quark interactions?
   It is called quantum chromodynamics, and it's a non-Abelian gauge theory, in which quarks interact through the exchange of colored gluons.
2. What was the first evidence of the existence of the structure of the nucleon?
   The first evidence of nucleon structure came from deep inelastic scattering of electrons from protons, it showed that protons have point-like objects inside.
3. By means of what do proton and electron interact in deep inelastic scattering?
   They interact by exchange of a virtual photon that carries large four-momentum.
4. How does the point-like structure of the proton appear in its structure functions?
   The structure function F_2 extracted from the experimental data remains constant over five orders of magnitude of Q^2.
5. What is the parton distribution function and how can we use it?
   The parton distribution function is the probability of finding a parton of a specific kind and momentum fraction in the hadron. We use them to apply the theory of quarks to hadrons.
6. Do parton distribution functions depend on Q^2?
   They depend on Q^2, but only slightly, logarithmically. And the evolution equations are quite different for sea quarks and valence quarks.

Main thoughts

Quarks cannot be observed on their own, neither do they have integer electric charges. Hence they were not believed to exist at first. But as experiments revealed a point-like structure of the proton, and as theorists provided a reasonable explanation of quark confinement, scientists started to consider quarks real. Later, three more quarks have been discovered, and a complete theory of six quarks grouped into three pairs, called quantum chromodynamics, was built. Within the theory, quarks have two major features resulting from the force carrier properties: asymptotic freedom and confinement. Another important effect of QCD is that apart from three valence quarks in the proton there are sea quarks and gluons. To describe them all, parton distribution functions were introduced and are now used to calculate hadron interactions.

Presentation speech

After many particles had been discovered in the 20th century, there was a need for an approach to describe all of them consistently. This is when the quark model was born. Despite its obvious success, it contradicted some fundamental expectations from a theory and was not immediately accepted. First, quarks did not exist outside hadrons and hence were unobservable. Second, quarks had non-integer electric charges, so the previously known elementary charge seemed to cease to be elementary. And third, there were baryons consisting of three quarks of the same flavor, and since quarks were fermions, it violated the very fundamental Pauli principle. However, the proton had to have a point-like structure seen in the deep inelastic scattering experiments of that time. So scientists throughout the world tried to solve all the problems mentioned above.

Of course, as we all now know, scientists did find the solutions, and a working theory was created. It introduced new force carriers, called gluons, that unlike photons, interact with each other. This causes some extraordinary effects acting as the solutions. First, when we try to pull apart two quarks, the gluon field between them, due to its own interaction, becomes tremendously strong and produces quark-antiquark pairs thus breaking the string and not letting any quarks be free. This property is called quark confinement. Second, since there are no free quarks, the old elementary charge stays elementary, and nothing contradicts all the old experiments about it. And third, what is not a result of gluon interactions, but more like a reason for them, quarks have an additional quantum number called color, which can take three values, and the color of all hadrons has to be neutral. This lets particles like the Δ^{++} resonance exist.

Since its first appearance, the quark model has been extended with three more quarks and now has three light quarks called u, d, and s, two heavy c and b quarks, and one super heavy t quark that decays so fast that it doesn't even have any bound states. This all led to the creation of an even more comprehensive theory, called quantum chromodynamics. It let us further understand the physics of quarks and hadrons. For example, it was found that a large portion of the hadron mass is created by so called sea quarks being produced inside the hadron due to gluon radiation.

This effect causes another difficulty for the description of hadrons. When we try to apply our beloved perturbation theory to the proton, we see that the contribution of sea quarks is more than 98%, and the series doesn't converge. However, when we consider heavy quarks and hadrons comprising them, we see that what was 98% for the proton is now only 6%, and this opens new possibilities to test whether our theory and understanding are correct or not.

What should also be mentioned is that we are not helpless to describe the structure of the proton. To consider all the quarks and gluons inside it, we can introduce momentum distributions called parton distribution functions. By means of them, at high energies, thanks to asymptotic freedom of quarks, we can calculate some properties and reactions. This way we can understand what exactly is in the proton. But as you can see, such situations are very specific and demand a lot from the experiment. And the results of experiments show that we are correct and our theory is correct, at least for today. Otherwise we wouldn't learn it.