Introduction to Nuclear and Particle Physics II

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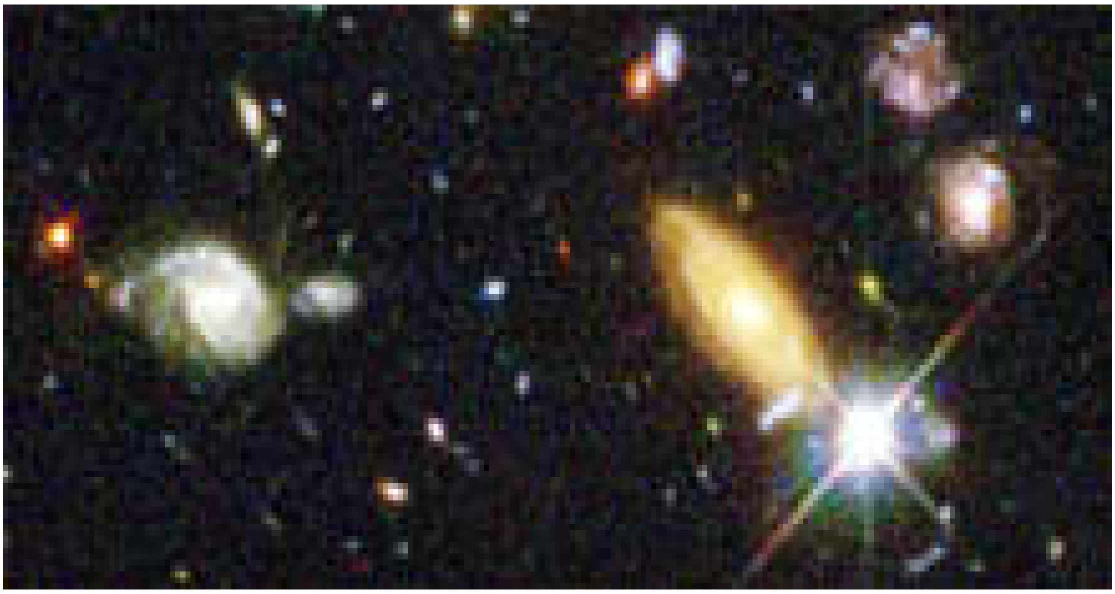
Abstract

In this presentation we will have and Introduction to Nuclear and Particle Physics and their applications in different areas.

Introduction



A Hubble Telescope photograph of galaxies deep in Universe

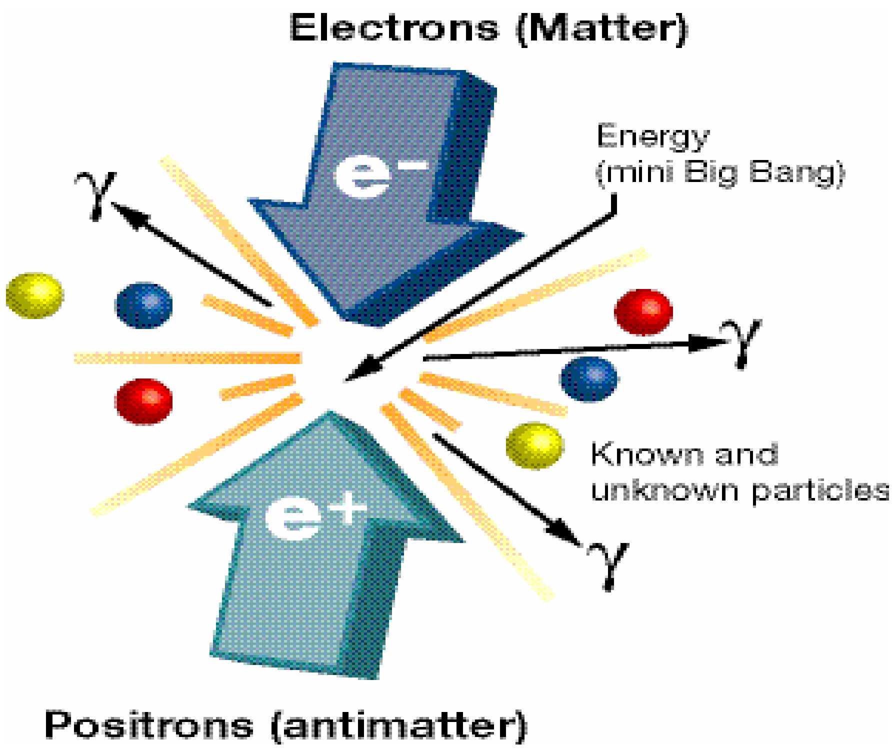
Here is our present understanding, in a nutshell. We believe that the Universe started off with a "Big Bang", with enormously high energy and temperature concentrated in an infinitesimally small volume. The Universe immediately started to expand at a furious rate and some of the energy was converted into pairs of particles and antiparticles with mass remember Einstein's $E= mc^2$. In the first tiny fraction of a second, only a mix of radiation (photons of pure energy) and quarks, leptons and gauge bosons existed. During the very dense phase, particles and antiparticles collided and annihilated each other into photons, leaving just a tiny fraction of matter to carry on in the Universe. As the Universe expanded rapidly, in about a hundredth of a second it cooled to a "temperature" of about 100 billion degrees, and quarks began to clump together into protons and neutrons which swirled around with electrons, neutrinos and photons in a grand soup of particles. From this point on, there were no free quarks to be found. In the next three minutes or so, the Universe cooled to about a billion degrees, allowing protons and neutrons to clump together to form the nuclei of light elements such as deuterium, helium and lithium. After about three hundred thousand years, the Universe cooled enough (to a few thousand degrees) to allow the free electrons to become bound to light nuclei and thus formed the first atoms. Free photons and neutrinos continue to stream throughout the Universe, meeting and interacting occasionally with the atoms in galaxies, stars and in us!

We see now that to understand how the Universe evolved we really need to understand the behavior of the elementary particles: the quarks, leptons and gauge bosons. These make up all the known recognizable matter in our Universe.

Beyond that, the Universe holds at least two dark secrets: Dark Matter and Dark Energy! The total amount of luminous matter (e.g., stars, etc.) is not enough to explain the total observed gravitational behavior of galaxies and clusters of galaxies. Some form of mysterious Dark Matter has to be found. Below we will see how new kinds of particles may be discovered that fit the description. Recent evidence showing that the expansion of the Universe may be accelerating instead of slowing down leads to the conclusion that a mysterious Dark Energy may be the culprit. Perhaps some new form of interaction may be responsible for that.

How do we get to study quarks and such, if they don't exist freely now?

Just as in the Big Bang, if we can manage to make high enough temperatures, we can create some pairs of quarks & anti-quarks, by the conversion of energy into matter. (Particles & anti-particles have to be created in pairs to balance charge, etc.)



When particles of matter and antimatter collide they annihilate each other, creating conditions like those that might have existed in the first fractions of a second after the big bang.

This is where high energy accelerators come in. In head-on collisions between high-energy particles and their antiparticles, pure energy is created in "little bangs" when the particles and their antiparticles annihilate each other and disappear. This energy is then free to reappear as pairs of fundamental particles, e.g., a quark-antiquark pair, or an electron-positron pair, etc. Now electrons and their positron antiparticles can be observed as two distinct particles. But quarks and antiquarks behave somewhat like two ends of a string you can cut the string and have two separate strings but you can never separate a string into two distinct "ends". Free quarks cannot be observed! So when a quark-antiquark pair is produced in a head-on collision with excess energy (i.e., **E > 2mq c2**) the quark and antiquark fly off in opposite directions until "the string breaks into two" and each of the pair finds itself bound with another quark. What we actually observe is a pair of mesons being produced, each meson consisting of a quark and an antiquark bound together. With enough excess energy, larger clumps of quarks and antiquarks can be produced: protons, neutrons and heavier particles classed as baryons. These mesons and baryons make up the zoo of particles discovered earlier.

What we have thus found is that to study quarks, one has to create them in high energy collisions, but they can only be observed clumped into mesons and baryons. We have to infer the properties of individual quarks through the study of the decay and interactions of these mesons and baryons.

The Standard Model

Particle physicists now believe they can describe the behavior of all known subatomic particles within a single theoretical framework called the Standard Model, incorporating quarks and leptons and their interactions through the strong, weak and electromagnetic forces. Gravity is the one force not described by the Standard Model.

The Standard Model is the fruit of many years of international effort through experiments, theoretical ideas and discussions. We can summarize it this way: All of the known matter in the Universe today is made up of quarks and leptons, held together by fundamental forces which are represented by the exchange of particles known as gauge bosons.

One guiding principle that led to current ideas about the nature of elementary particles was the concept of Symmetry. Nature points the way to many of its underlying principles through the existence of various symmetries [1].

Looking to the Future

One of the primary goals for the new and upgraded facilities in Fermilab near Chicago (the Tevatron) and CERN in Geneva Switzerland (the Large Hadron Collider or LHC) is to find the Higgs boson, the one missing element of the Standard Model.

Evidence for supersymmetric partners of the known particles is a goal in all experiments, as part of the search for the true particle theory beyond the Standard Model. Beyond that is the need to find anything that can point to a real Grand Unification with the gravitational force.

A different kind of e+ e- collider is being planned internationally the International Linear Collider or ILC, a very high energy linear collider, with two opposing linear accelerators tens of kilometers long. The technical challenges are many and this is likely to be the first truly world-wide accelerator collaboration.

Reference

[1]- Fayyazuddin Riazuddin, A Modern Introduction to Particle Physics, World Scientific, 2000