PHYSICS 205
Relativistic Quantum Field Theory

Prerequisites: Quantum Mechanics (e.g., Landau + Lifshitz
Electricity + Magnetism (e.g. Jackson)

Books (Recommended):
P. Ramond, Field Theory, Benjamin/Cummings
C. Itzykson + J. Zuber, Quantum Field Theory, McGraw-Hill

(The lectures, not the books, are the basis of the course.)

Requirements: Problem Sets

Grading: Pass/Fail

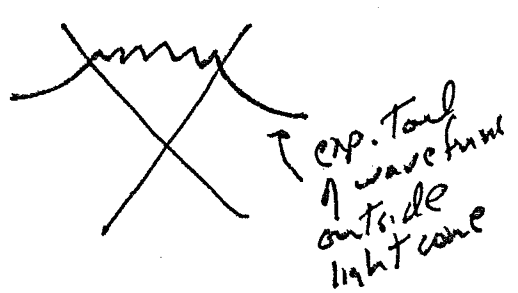
The goal of the course is to provide an introduction to modern particle theory -- the "standard model." The course will not review the detailed experimental evidence in favor of the standard model; that is the task of Physics 231. Nor will it examine the detailed consequences and predictions of the model; for that take Physics 230 or 234. Rather, this course is intended to provide an introduction to the methodology of quantum field theory. You'll learn enough formalism to understand what the standard model is, and the technical tools needed to perform calculations,

Introduction and Motivation

Relativistic quantum field theory is the outcome of attempts to join the principles of special relativity and quantum physics; in particular, to describe the interactions of ("elementary") particles while taking relativity and quantum mechanics fully into account.

If our primary interest is really in particles, why do we bother to introduce fields? Even classically (e.g. E+M) the need for dynamical fields arises if we wish to describe the interactions of particles in a manner consistent with causality, i.e., without action at a distance.

But, in classical electromagnetism, the fundamental dynamical variables are fields and charged particles. In quantum field theory, only fields are regarded as fundamental entities, and particles arise from quantization of fields. Why this extra step? In quantum mechanics, the need for fields in describing interactions consistent with relativity is even more desparate than in classical physics. A fundamental conflict must be resolved, between locality, and the uncertainty principle. If particles cannot be perfectly localized, what is to prevent information from leaking outside the light cone? We will see that, with fields as the dynamical variables, we can more readily construct theories that are naturally local.



Ordinarily, symmetries simplify problems (consider rotational invariance in solution to the hydrogen atom.) Why then, is relativistic quantum physics, quantum mechanics consistent with Lorentz invariance, notoriously difficult? The key difficulty is that relativistic quantum theory necessarily means field theory, and a field has an infinite number of degrees of freedom. That is really the crucial difference between particle quantum mechanics and relativistic particle mechanics, the difference between a finite and infinite number of degrees of freedom. In perturbation theory, excitations of all the degrees of freedom can occur as intermediate states. This means that (1) the perturbation expansion is complicated, and (2) there may be convergence problems in the sum over intermediate states. Infinities can occur, and the interpretation of these infinities is a subtle matter.

A final note before we begin in earnest: there is another way of constructing a consistent relativistic quantum theory, involving strings rather than (pointlike) fields. Moreover, this alternative approach seems to encompass a quantum theory of gravity (never successfully formulated in the old field theory framework), and, in fact, a unified description of all interactions. Does that mean, then, that the topic of this course is about to become obsolete, to be supplanted by string theory? Fortunately, no. It is very important to understand that a field theory can be useful, and the basis of very accurate calculations, even if it has no claim to being a fundamental description of physics at arbitrarily short distances. Old fashioned "pointlike" field theory, the topic of this course, will prove useful in the future, as it has in the past, as we attempt to probe the "low-energy" consequences of the string theory (or whatever theory gives the correct description at $L_{\text{planck}} \sim 10^{-33}$ cm.)

1. The Free Scalar Field

2. Interacting Scalar Fields

3. Spin 1/2

4. Functional Integration

5. Quantum Electrodynamics

6. Spontaneous Symmetry Breakdown

7. Nonabelian Gauge Fields