Dubravko Klabučar:

Relativistic quantum physics

– summary of the course with syllabus/overview of study topics:

Summary:
This fourth-year winter-semester course provides the bridge between the third year (non-relativistic) quantum mechanics course and the fourth-year, summer-semester first field theory course. It starts from one-particle relativistic quantum mechanics – i.e., the relativistic quantum mechanics "in the narrow sense". It is developed and its most notable successes are stressed, but also its limitations are pointed out and explained, clarifying the need for quantum fields. The contact with the quantum-field-theory reasoning is established by developing Feynman propagator techniques to treat relativistic scattering processes and to introduce Feynman rules and diagrams for quantum electrodynamics.

Syllabus - overview of study topics (divided tentatively in 15 teaching weeks in the semester):

1.) The need for formulating a relativistic quantum theory. Transition from the non-relativistic to relativistic quantum mechanics.

2.) The relativistic quantum-mechanical equation for spin-0 bosons: Klein-Gordon equation, some applications and some problems.

3.) The relativistic quantum-mechanical equation for spin-1/2 fermions: Dirac equation for 4-component spinors. Non-relativistic limit, Pauli equation, spin, the electron magnetic moment and gyromagnetic ratio of 2.

4.) Lorentz covariance of Dirac equation, gamma matrices and their properties. Bilinear covariants of Dirac spinors.

5.) Solutions of the free Dirac equation. Projection operators of energy and spin.

6.) Wave packets of plane Dirac waves. Non-conservation of spin and orbital angular momentum, conservation of the total angular momentum and helicity.

7.) Dirac particle in the central field. The 4-component Dirac spinors expressed through Pauli central-field spinors.

8.) Dirac equation for hydrogen and hydrogen-like systems with Coulombic interaction. The relativistic energy spectrum of the hydrogen atom.

9.) On some motivations for quantum field theory such as Lamb's shift and the need for corrections to the gyromagnetic ratio.

10.) Dirac theory of positrons and other antiparticles. Charge conjugation, parity and time inversion.

11.) Propagator theory and scattering theory.

12.) Feynman propagator of spin ½ fermions. Photon propagator.

13.) Scattering in quantum electrodynamics, Feynman rules.

14.) Connection of so obtained Feynman rules with the canonical quantization of the electromagnetic field and fermion fields.

15.) Some lowest-order processes in electrodynamics in the lowest order of the coupling, tree Feynman diagrams.

- general and specific knowledge gained within the course:

Knowledge of the basic concepts of relativistic quantum physics – relativistic wave equations for spin-0 and spin-1/2 particles, the essential properties of these equations and of their solutions for a free particle and for some bound states with Coulomb interaction. The Feynman propagator formalism is introduced and then mastered by using it to perform the transition from the single-particle relativistic quantum mechanics to quantum electrodynamics (as the prime example of a quantum field theory). The Feynman rules are introduced and learned by applying them to the simplest examples of scattering in quantum electrodynamics.