Physics 615: Overview of QFT **Fall 2010**

TENTATIVE SYLLABUS

This is a tentative schedule of what we will cover in the course. It is subject to change, often without notice. These will occur in response to the speed with which we cover material, individual class interests, and possible changes in the topics covered. Use this plan to read ahead from the text books, so you are better equipped to ask questions in class.

INTRODUCTION

• **Classical Field Theory:** Lagrangian density. Example: Continuum limit of a one dimensional lattice. Lorentz invariance. Locality and causality. Equations of motion.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapter 2.2)
2) H. Goldstain: Classical Mechanics, Addison-Wesley, 3d edition (Chapters 13.1, 13.2)
3) L.D. Landau and E.M. Lifshitz: The Classical Theory of Fields, Buterworth Heiemann, 4th ed (Chapter 1-7)

• **Noether's Theorem:** Symmetry. Noether's theorem. Energy-momentum tensor. Examples.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapter 2.2)
2) H. Goldstain: Classical Mechanics, Addison-Wesley, 3d edition (Chapters 13.3, 13.5, 13.7)
3) L.D. Landau and E.M. Lifshitz: The Classical Theory of Fields, Buterworth Heiemann, 4th ed (Chapter 26-33)

• **Klein-Gordon Field:** Hamiltonian formalism. Quantization. Fock space. Spectrum. Causality and local commutativity in QFT. Feynman propagator.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 2.3, 2.4)
2) H. Goldstain: Classical Mechanics, Addison-Wesley, 3d edition (Chapters 13.4, 13.6)

THE DIRAC FIELD

• **Representations of the Lorentz group:** Representations of the infinitesimal Lorentz group. Left- and right- handed spinors. Vector representations. Space Inversions and Time-Reversal. The Dirac spinor. Dirac spinor bilinears. Algebra of the Dirac matrixes.

Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 3.1, 3.2, 3.4)

2) P. Ramond: Field Theory. Published by Westview Press, 1997 (2d edition) ISBN 0201304503, 9780201304503 (Chapters 1.2, 1.4)

3) L.D. Landau, E.M. Lifshitz, V.B. Berestetskii and L.P. Pitaevskii: Quantum Electrodynamics (Course of Theoretical Physics, Volume 4) Buterworth Heiemann, 2nd ed (Chapters 3.17-3.19, 3.22)

• **The Dirac equation:** The Dirac and Weyl Lagrangians. Free-particle solutions of the Weyl equation. Helicity. Free-particle solutions of the Dirac equation. Spin sums.

Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 3.1-3.3)

2) L.D. Landau, E.M. Lifshitz, V.B. Berestetskii and L.P. Pitaevskii: Quantum Electrodynamics (Course of Theoretical Physics, Volume 4) Buterworth Heiemann, 2nd ed (Chapters 3.20, 3.21, 3.23, 3.30)

• **The quantized Dirac field:** The canonical quantization of the Dirac field. The relation between the spin and the statistics. The Dirac propagator. Grassmann numbers.

Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapter 3.5)

2) L.D. Landau, E.M. Lifshitz, V.B. Berestetskii and L.P. Pitaevskii: Quantum Electrodynamics (Course of Theoretical Physics, Volume 4) Buterworth Heiemann, 2nd ed (Chapter 3.25)

• **Discrete symmetries of the Dirac theory:** Symmetries in the quantum system. Parity. Time reversal. Charge conjugation. CPT-theorem.

Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 3.6)

2) L.D. Landau, E.M. Lifshitz, V.B. Berestetskii and L.P. Pitaevskii: Quantum Electrodynamics (Course of Theoretical Physics, Volume 4) Buterworth Heiemann, 2nd ed (Chapters 3.26-3.28)

3) S. Weinberg, The Quantum Theory of Fields, Cambridge University Press, Vol.1 (Chapters 2.1-2.3)

4)[1] R.F. Streater and A.S. Wightman; PCT, spin and statistic and all that. Princeton University Press, 2000 ISBN 0691070628, 9780691070629

PERTURBATION THEORY

• **Interacting fields:** Perturbative QFT. Relevant, marginal and irrelevant perturbations. Examples: ϕ^4-theory, Yukawa theory, QED.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapter 4.1)

• **Formal perturbative expansion of correlation functions:** Interaction picture. Dyson series. Wick's theorem. Feynman diagrams for ϕ^4-theory. Symmetry factors. Disconected (vacuum) diagrams. Diagramology: Fully connected and "amputated" correlation functions, proper verteces. Momentum-space Feynman rules.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 4.2-4.4)

• **Ultraviolet divergencies in ϕ^4-theory:** Mass operator at the lowest perturbative order. Wick rotation. Mass renormalization. Counting of ultraviolet divergences. Renormolized coupling constant. Field-strength renormalization.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 10.1, 10.2)

• **Renormalized perturbation theory:** enormalization programm. Interacting fields in d-dimensions. Dimensional regularization. Renormalization schemes. Renormalization at the leading order in ϕ^4-theory.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 10.1, 10.2, 7.7 (pp.249-251))

• **Renormalization group equation:** The massless ϕ^4-theory. Renormalization scheme. "Critical" submanifold. Callan-Symanzik equation. Renormalization group flow. Running coupling constant.

[1] Advanced Book Classics

Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 12.2, 12.3)

• **Theories with fermions:** Wick theorem. Feynman rules for fermions. Overwiew of renormolized perturbation theory for the pseudoscalar Yukawa theory.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 4.7, 7.5 (pp.249-251))

SCATTERING THEORY

• **Asymptotic theory:** Spectral assumptions. Kallen-Lehmann spectral representation. In- and out- states. S-matrix. The LSZ reduction formula. Computing S-matrix elements from Feynman diagrams. Rates and cross sections.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 7.1, 7.2, 4.5, 4.6);
2) S. Weinberg, The Quantum Theory of Fields, Cambridge University Press, Vol.1 (Chapters 3.1, 3.2, 3.4, 3.5);
3) C. Itzykson, J.-B. Zuber, Quantum Field Theory, McGraw-Hill International Editions [IZ], Vol.1 (Chapter 5);
4). R.F. Streater and A.S. Wightman; PCT, spin and statistic and all that. Princeton University Press, 2000 ISBN 0691070628, 9780691070629

• **Examples of S-matrix:** Simplest scattering amplitudes for ϕ^4 and Yukawa theories. Mandelstam variables. Nonreletevistic limit.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 4.5-4.7);

• **Elementary processes of QED:** Feynman Rules for QED. The Coulomb Potential. $e + e^+ \to \mu + \mu^+$ and $e + \mu \to e + \mu$ cross secrtions. Compton scattering.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 1, 4.8, 5.1-5.3, 5.5);

• **General properties of S-matrix:** Crossing symmetry. C, P, T -invariance. Optical theorem.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 5.4, 7.3);

2) S. Weinberg, The Quantum Theory of Fields, Cambridge University Press, Vol.1 (Chapters 3.3, 3.6);

QED

• **UV divergencies:** Current correlation functions. Counting of the UV divergencies. Photon polarization operator. Non-renormalizability of the conseved current. Renormalized perturbation theory. Normalization conditions.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 10.1, 10.3, 7.5);

• **Radiative corrections:** Electron-photon vertex and two particle form factors of the current. Schwinger's correction. Infrared divergencies.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 6.1-6.5, 7.3);

• **Gauge invariance:** Electron self-energy. Ward-Takahashi identities.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 7.1 (pp.217-222), 7.4;

• **UV asymptotics:** Vacuum polarization. Callan-Symanzick equation. Running coupling constant. Landau pole.
Literature: 1) M.E. Peskin, D.V. Schroeder: Quantum Field Theory (Chapters 7.5, 12.2);