Progress in quantum field theory course

Jan 19 - **Basics 1** – constructing a field, mass points, continuum limit, Lagrangian for the field, the wave equation, quantum commutation rules, solving with creation operators, quanta.

Jan 21 - **Basics 2**– Solving the Hamiltonian, States and quanta, why equal time commutators, connection to normal modes, continuous momentum notation, the Quantum Field, taking matrix elements, intuition

Jan 26 - **Basics 3** – inverting the field, conservation of energy, the momentum operator, natural units, four vectors, dimensional analysis

Jan 28 - **Introducing the fields 1** – listing the common fields, the real scalar field, more general lagrangian, why phonons are massless, Feynman propagator, representation in terms of solutions, Fourier integral representation.

Feb 2 – **Introducing the fields 2** – i epsilon physics, intuition on propagator, zero point energy, the complex scalar field, quantization, conserved charge and current, particles and antiparticles.

Feb 4 – **Introducing the fields 3** – the Schroedinger Lagrangian, non-relativistic reduction, quantization, Fermions, Review of the electromagnetic field, quantization, propagator

Feb 9 **– Introducing fields 4** – the Dirac Lagrangian, Hamiltonian, useful identities, quantization, the particle number current, the Dirac propagator.

Feb 11 **– Interactions 1 –** the covariant derivative and interactions in E&M, gauge invariance, identifying the electromagnetic current, matrix elements of the current, transition matrix elements, Rules for matrix elements

Feb 18 – **Interactions 2 -** -crossing, Dirac rules, other interactions, perturbation theory plan, review of the interaction picture and the time development operator, first example scattering amplitude in φ^4

Feb 23 – **Interactions 3** – review, toy model for QED, matrix elements with propagator, connections to first Born approximation and to QM perturbation theory, Wick's theorem.

Feb 25 **– Interactions 4** – Feynman rules for $\varphi^{4,}$ second order example, self energies, disconnected diagrams, loop integrals, dropping disconnected diagrams, Feynman rules for other theories, photons and fermions.

Mar 2 – **Calculating 1 –** Review of Feynman rules, plan for "Calculating section", decay rate and cross section formulas, review of Fermi's Golden Rule, adapting FRG to field theory decay rates, using FGR for cross sections.

Mar 4 **– Calculating 2** – Identical particle effects, generalization to more particles, Lorentz invariant phase space, cross section for φ^4, correspondence to non-relativistic results, low energy expansion of a propagator, QED scattering cross section

Mar 9 – **Calculating 3** – review of Feynman rules for Dirac particles, finishing QED cross section – connection to non-relativistic QM, Noether's theorem, calculating the Noether current, example, spacetime symmetry and the energy momentum tensor, interactions and symmetries.

Mar 11 – **Calculating 4** – Ground state energies and masses, symmetry breaking and Goldstone's theorem, calculating with two different names for the fields, example, names don't matter – Haag's theorem, the Higgs mechanism

Week of March 21 – the following two lessons are to be watched online:

Renormalization 1 – the philosophy of renormalization: measuring the electric charge, expressing cross-section in terms of measured value, the bare charge and the physical charge, the counterterm method for QED, renormalizing phi-phi scattering.

Renormalization 2 – calculating a loop integral: Feynman parameterization, completing the square, Wick rotation, 4 dimension spherical coordinates, the final integral and results.

Mar 30 - **Renormalization 3** – review, two procedures for renormalization, imaginary parts, unitarity, useful identities, infinities, why quantum calculations work, philosophy of infinities

April 1 - **Renormalization 4** – regularization, Pauli-Villars (with example), dimensional renormalization, gamma function review, calculation of loop integral, expansion about d=4.

April 6 – **Renormalization 5** – mass renormalization, wavefunction renormalization, logic and formal techniques, general techniques, renormalizable and nonrenormalizable theories, example of issues with nonrenormalizable theories

April 8 **– QED 1** – QED, charge quantization, gauge invariance in matrix elements, the renormalization program, fermion mass and wavefunction renormalization, the vacuum polarization, calculating the vacuum polarization, photon wavefunction renormalization.

April 13 – **QED 2 –** review, diagrams for charge renormalization, the vertex function, the full charge renormalization, residual predictions, the running coupling, the Lamb shift

April 15 – **QED 3** – infrared divergences, solution via bremsstrahlung, Lamb shift and off-shell g=2 in Dirac theory, Gordon decomposition, calculation of g-2, practical group theory.

April 20 – **QED 4** – SU(N) group theory, SU(N) gauge theory, the gauge covariant derivative, the field strength tensor, the Yang-Mills lagrangian, interactions, examples and **Path Integrals 1** – Gaussian integrals needed for functional methods

April 22 **– Path Integrals 2** – example for functional methods, PI in quantum mechanics, derivation, wavefunctions and matrix elements, projecting out the ground state, functional differentiation, the generating functional, Example: the harmonic oscillator

April 27 – **Path Integrals 3** – review of QM work, path integral for fields, functional differentiation again, Greens functions, solving the free field generating functional, the two point function, the four point function

April 29 – **Path Integrals 4** – Interactions in PI framework, perturbative expansion, working to first order in λ, the two point function and the propagator, the four point function and the scattering amplitude, the generating functional contains all amplitudes, the LSZ reduction formula

May 4 – **Path Integrals 5** – Connections between Path Integrals and quantum statistical mechanics, quantum mechanics and quantum field theory, effective field theory, integrating out heavy fields, Wilsonian version of renormalization group