# Quantum Field Theory I: Fall 2021

**M-W-F 3:00 pm →3:50 pm: 106 Allen Hall**

**Instructor: Daniel Boyanovsky 208 Allen Hall,**
**boyan@pitt.edu, (412)-624-9037 (office)**

## SYLLABUS:

Basics of field quantization: from particles to fields, from fields to particles. Lagrangian and Hamiltonian dynamics: Euler-Lagrange equations, Poisson brackets. Field quantization: Elastic waves: phonons, the continuous string: a real scalar field. Quanta as particles. Relativistic QFT: brief review of special relativity. Lorentz transformation laws for fields. Causality. Symmetries and conservation laws: Noether's theorem, the energy momentum tensor, conserved currents and symmetry generators. Topological conservation laws: solitons. The relativistic real and complex Klein-Gordon (scalar) fields (Higgs field): global gauge symmetry. Microscopic causality and commutators. Green's functions: advanced, retarded and Feynman. Applications: i) linear response, ii) particle production by external sources, iii) effective field theory and interactions. Interlude: Second quantization of the Schroedinger field: non-relativistic many body physics. Quantized electromagnetic field: photons: (spin 1) gauge invariance, physical degrees of freedom, microscopic causality and propagators. The massive vector field (Proca) (W,Z gauge bosons) the propagator. Effective field theory: massive vector boson exchange: effective low energy field theory.

Dirac field: Dirac equation, non-relativistic limit, minimal coupling and correct gyromagnetic factor. Spin ½. Helicity. Quantization, Anti-commutators: the Pauli exclusion principle. Spin statistics connection. Weyl and Majorana fermions. Antiparticles. Propagators. Connection to CM: graphene and Weyl semimetals. Minimal coupling between electromagnetic and charged fields and gauge invariance. Gyromagnetic factor of the electron and Thomas factors.

Interacting fields discrete symmetries, parity, charge conjugation and time reversal, intrinsic parity. PCT theorem. P and C violation in weak interactions: the Co60 expt. S-matrix. Feynman diagrams/calculus: Wick's theorem. Cross sections and decay rates: examples. Unitarity. Disconnected (vacuum) diagrams Quantum electrodynamics: elementary processes: cross sections: Casimir ``trick''. Self-energy corrections, Dyson series and resummation: effective propagators. Examples. Resonances: Breit-Wigner propagators and resonant cross sections. Interpretation of the time evolution. Loops: scalar field theory, regularization: dimensional regularization. Renormalization in QED: Ward identities, dimensional regularization, g-2, Lamb shift effective running coupling: screening. Dressed electrons. Renormalized perturbation theory: counterterms. Dressing by virtual excitations, Gell-Mann-Low theorem. Quasiparticles.
Asymptotic states: in-out formulation of S-matrix elements. Correlation functions and their relations to cross sections. Structural aspects: spectral representations and dispersion relations.

## Brief description of QFT II:

Non-abelian gauge theories: QCD, asymptotic freedom and confinement. Spontaneous symmetry breaking, Goldstone modes, Higgs Mechanism. Connections with condensed matter: Meissner effect in superconductivity. Symmetry breaking in the Standard Model, the Higgs mechanism and origin of masses.
Path integral quantization and connection to statistical mechanics. Gauge theories in the path integral formulation. LSZ formalism, from path integrals to cross sections. Renormalization group.

Useful books: I will draw material from many different books: QFT and the Standard Model, by M. Schwartz, QFT by Peskin/Schroeder, Relativistic QM and field theory: F. Gross, QFT by Mandl and Shaw, any of the more recent books will do. I will share my class notes (see below).

## FORMAT OF THE CLASS:

**Format of the course:**

**After each class I will send a pdf with the class notes for the day.**

One homework problem set (4-5 problems) per week, one take home midterm and a take home final. The final grade is the average of HM+mid+final.
All homework and exams should be clearly written and explained, no work shown = no grade!, please label equations. No need for fancy typesetting, just handwritten clearly will do!.

**PROTOCOL:** Homework and exams MUST be submitted via e-mail as **PDF files** which will be returned with grades and corrections. Please send small (compressed) pdf files!!. Work should be individual, I can be consulted (see below).

**OFFICE HOURS AND CONSULTATIONS:** In accordance with health guidelines and social distancing protocols, in person office hours will be restricted by appointment only. For appointments: send me an e-mail with possible (prioritized) meeting times, I will try to accommodate your requests.

I will be available via e-mail every day and commit myself to answering all questions within 24 hours. If needed we can schedule a ZOOM meeting if there is no suitable in-person arrangement with prior appointment.