

Physics 610: Quantum Field Theory I

Fall 2013

Instructor: George Sterman
(MT-6108, george.sterman@stonybrook.edu)

Room: Physics P-128 TuTh 8:30-9:50 First Meeting: Tuesday, Aug. 27

This course will introduce quantum field theory, emphasizing concepts that underlie the standard model of elementary particles, as well as many methods in condensed matter physics. We will attempt both to survey the fundamental ideas and results, and to lay the groundwork for more advanced study. Concepts and methods to be discussed will include:

- Classical and quantum symmetries
- Second quantization
- Particle interpretation, free fields, the S-matrix and cross sections
- Perturbative expansions
- Representations of the Poincaré group; & supersymmetry
- The Dirac equation
- Nonrelativistic fermion fields; quasiparticles
- Abelian and nonabelian gauge theories, QED and QCD
- Spontaneous symmetry breaking the Higgs mechanism
- Concepts of renormalization
- Basic tests of the standard model and searches for new physics

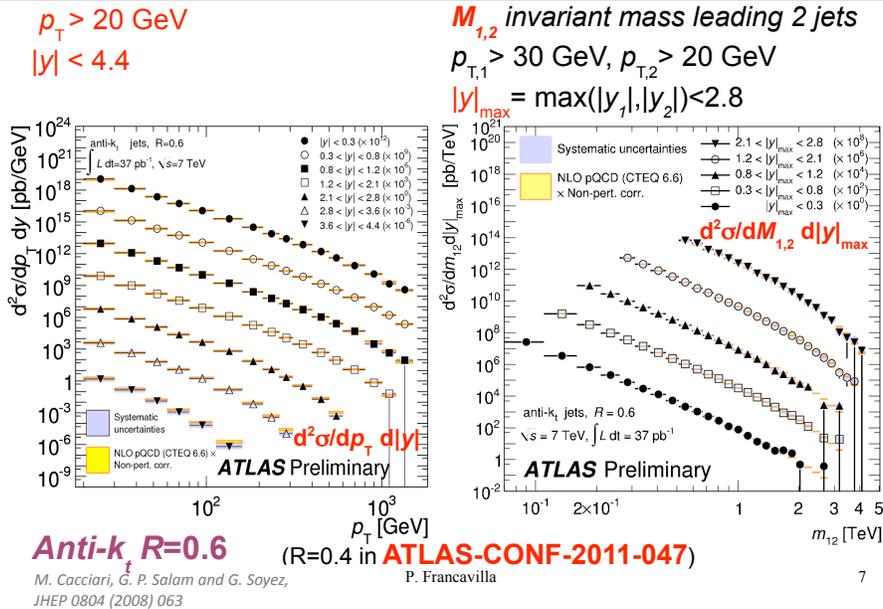
In Phys. 611, the above methods will be further developed, along with:

- Path integrals in quantum field theory
- Ultraviolet divergences, dimensional and other regularizations
- Renormalization, renormalization group and effective field theories
- Perturbative unitarity and the infrared problem in QED and QCD
- The operator product expansion, factorization and evolution
- Chiral symmetries and the axial anomaly

The discussion of most, but not all, of the above topics will follow my book, *An Introduction to Quantum Field Theory*, which, however, is by no means required. The emphasis will be on relativistic field theories and high energy physics, but we will try to make contact with other applications as well.

To give a preliminary idea of the relevance of quantum field theory itself, we may ask at what length scales it is likely to be applicable to natural phenomena. In this connection, consider the following quote from the 1966 book *Relativistic Quantum Fields*, by Bjorken and Drell, regarding the status of the wave, i.e. field, concept at short distances, “. . . it is a gross and profound extrapolation of present experimental knowledge to assume that a wave description successful at ‘large’ distances (that is, atomic length $\sim 10^{-8}$ cm) may be extended to distances an indefinite number of orders of magnitude smaller (for example, to less than nuclear lengths $\sim 10^{-13}$ cm).” In the time since this was written, experiments have justified the use of field theories (the standard model) to length scales a thousand times smaller than nuclear lengths, up through experiments at the Fermilab Tevatron and now the LHC, which probe the predictions of field theory to a fraction of $10^{-16} - 10^{-17}$ cm. The predictions of the standard model still hold up.

Cross Section: Inclusive single and di-jet



For example, the figure shows the single-jet cross section, which is closely related to quark-quark scattering, reported by the Atlas Collaboration at the 2011 Europhysics Conference, up to momentum transfers (labelled by p_T ; η is related to the scattering angle) of over 1 TeV (10^{12} eV). This cross section depends directly the behavior of the standard model at length scales of nearly 10^{-17} cm. The application of field theory to experiment is not a closed book. In fact, many – but not all – theoretical considerations suggest that a field theoretic picture description, extending the standard model, should be valid nearly to the Planck scale ($\sim 10^{-32}$ cm).

3. Grades

A grade for this course will reflect the results of midterm and final examinations, homework and a short paper. Homework will be assigned each week, and will be due at the lecture one week later, except when otherwise arranged. The timing and procedures of the midterm exam will be arranged. The final exam is scheduled for Tuesday Dec. 10, 11:15-1:45 pm.

4. Office Hours; Recitations

I should be available for discussion after class, and in my office 2-4 PM on Tuesday afternoons. I'm there most of the time anyway, so you might drop by, but I may not be available at all other times. Recitation sessions may be arranged in response to demand.

5. For Your Consideration:

University policy prescribes that the following information be included in all course syllabi.

Americans with Disabilities Act: If you have a physical, psychological, medical or learning disability that may impact your course work, please contact Disability Support Services, ECC(Educational Communications Center) Building, Room 128, (631)632-6748. They will determine with you what accommodations, if any, are necessary and appropriate. All information and documentation is confidential.

Academic Integrity: Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty are required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Technology & Management, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty, please refer to the academic judiciary website at <http://www.stonybrook.edu/uaa/academicjudiciary/>

Critical Incident Management: Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of University Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures. Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.

6. There is no required text. Recommended Books on Reserve in Math-Physics Library include those below.

Others may be put on reserve as appropriate.

- J.D. Bjorken and S.D. Drell, *Relativistic Quantum Mechanics and Relativistic Quantum Fields*, 1966. A classic; follows a very different route than ours.
- C. Itzykson and J.B. Zuber, *Quantum Field Theory*, 1980. A lot of material, a lot of pages: small print, and smaller print. Has a treatment of renormalization of gauge fields based on generating functional formalism.
- M.E. Peskin and D.V. Schroder, 1995, *Introduction to Quantum Field Theory*.
- P. Ramond, *Quantum Field Theory, a Modern Primer*, 1981. Not so modern any more, but succinct and to the point. Good, streamlined treatment of ϕ^4 renormalization. One of the few texts to have an introduction to the Poincaré group.
- G. Sterman, *An Introduction to Quantum Field Theory*, 1993. My book; the one we will mainly follow.
- M. Srednicki, *Quantum Field Theory*, 2007.
- S. Weinberg, *Quantum Theory of Fields*, 1995. Vols. 1, 2. Emphasizes some of the same issues as in our course, but at a mathematically more rigorous level. What Weinberg has to say is always worth reading.