Introduction to Elementary Particle Physics

Physics 622, Fall 2002

Physics 622, Introduction to Elementary Particle Physics, will be offered in Fall 2002. This course is recommended for both theory and experimental students in particle physics. The course will involve a thorough exploration of the structure of the standard model, the associated phenomenology, the field-theoretic calculational techniques, and some discussion of beyond the standard model possibilities.

Classes will be held on Mondays and Fridays from 11:00-12:30, starting Friday Sept. 6 through Monday, Dec. 9. They will be held in Towne 319, which is a specialized classroom with video-conferencing facilities. Students at Fermilab will be able to participate remotely from the CDF video-conferencing facility, reserved MF from 10:00-11:30. There may also be a Princeton link. Walt Kononenko (215-898-7572, wk@upenn5.hep.upenn.edu) will coordinate the videoconferencing.

The major topics will be

- Review of perturbative field theory
- Lie groups and algebras
- Nonabelian gauge theories
- Quantum Chromodynamics
- The standard electroweak theory
- Beyond the standard model (e.g. supersymmetry, grand unification)

Each section will include relevant formalism, phenomenology, and experimental results. A more detailed syllabus is given below.

The course will loosely follow chapters 5-10 of the book *Electroweak Interactions* by Peter Renton.

There are no formal prerequisites. However, a working knowledge of Feynman diagrams for fermions, photons, and scalars will be assumed, equivalent to chapters 3 and 4 of Renton. Elementary background in particle physics and other topics equivalent to chapter 1 and the first four sections of chapter 2 will also be assumed.

Syllabus

The tentative syllabus is given. It may be necessary to eliminate some topics.

- Review of perturbative field theory
  - Lagrangians, propagators, and Feynman rules for real and complex scalars, fermions, and massless and massive vector fields
  - Cross section and decay width formulae
  - Tree level examples from ϕ^3, ϕ^4, πN (without isospin), scalar and fermion electrodynamics, eP with form factors, hyperon decays, weak νe processes
  - Loop effects
  - QED overview
- Lie groups and algebras
  - Basic concepts
  - $SU(2)$ and $SU(3)$
  - Global symmetries in field theory
  - Explicit and spontaneous breaking; the Goldstone theorem
- Nonabelian gauge theories
  - Abelian gauge symmetries
  - Structure of non-abelian gauge symmetries
  - Feynman rules without spontaneous breaking
- Quantum Chromodynamics
  - Lagrangian and rules
  - Asymptotic freedom and infrared slavery
  - Short distance physics
    - $e^+e^- \to$ hadrons
    - Deep inelastic scattering
    - High p_T hadron scattering
  - Long distance physics
    - Confinement
    - The flavor symmetries $SU(2)$, $SU(3)$
    - Chiral symmetry

- The standard electroweak theory
  - The Fermi and IVB theories
  - Weak processes: μ decay, β decay, $\pi_{l2,3}$ decays, strangeness, Cabibbo theory
  - Discrete symmetries P, C, CP, T
  - The $SU(2) \times U(1)$ model
    * Basic structure
    * The Higgs mechanism
    * The Lagrangian after SSB
  - Consequences and tests
    * Gauge interactions of fermions, weak neutral current
    * Gauge bosons and their self-interactions
    * The Higgs sector
    * The CKM matrix
    * K and B physics, penguins, heavy quark expansion, CP violation
  - Neutrino mass and implications
    * Neutrino mass mechanisms
    * Neutrino oscillations
    * Neutrinoless double beta decay
    * The neutrino spectrum
- Beyond the standard model
  - Motivations
  - Unification or compositeness
  - Extended gauge groups and exotics
  - Grand Unification
  - Supersymmetry (qualitative)
  - Strings (qualitative)

Bibliography

- Text: P. Renton, *Electroweak Interactions: An Introduction to the physics of Quarks and Leptons* (Cambridge University Press, Cambridge, 1990)
- Supplementary materials on web
  - The Review of Particle Properties, 2002, http://pdg.lbl.gov/, especially the review articles on QCD, Electroweak Theory, and other Standard Model topics.
  - Structure of the Standard Model, from *Precision Tests of the Standard Electroweak Model* (World, Singapore, 1995) ed. P. Langacker.
- Recommended books (on reserve)
  - I. J. R. Aitchison and A. J. G. Hey, *Gauge Theories in Particle Physics*, (Adam Hilger, Bristol, 1989).
  - C. Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions* (Benjamin, Menlo Park, 1983).
  - T.-P. Cheng and L.-F. Li, *Gauge Theory of Elementary Particle Physics* (Clarendon, Oxford, 1984).
  - V. D. Barger and R.J.N. Phillips, *Collider Physics* (Addison-Wesley, Reading, 1997).
  - F. Halzen and A. D. Martin, *Quarks and Leptons : an Introductory Course in Modern Particle Physics* (Wiley, New York, 1984).
- Other recommended books
  - L. B. Okun, *Particle physics– the quest for the substance of substance* (Harwood, New York, 1985) – introduction.
  - D. H. Perkins, *Introduction to high energy physics* (Addison-Wesley, Menlo Park, 1987) –experimentally oriented.
  - F. Mandl and G. Shaw, *Quantum Field Theory* (Wiley, Chichester, 1984).
  - L. H. Ryder, *Quantum Field Theory* (Cambridge, Cambridge, 1996).
  - J. D. Bjorken and S. D. Drell, *Relativistic Quantum Mechanics* (McGraw-Hill, New York, 1964); *Relativistic Quantum Fields* (1965).
  - M. E. Peskin and D. V. Schroeder, *An introduction to quantum field theory* (Addison-Wesley, Menlo Park, 1995).
  - J. F. Donoghue, E. Golowich, B. R. Holstein, *Dynamics of the standard model* (Cambridge, Cambridge, 1992) – symmetries, current algebra, etc.

– E. D. Commins and P. H. Bucksbaum, *Weak interactions of leptons and quarks* (Cambridge, New York, 1983) – still the classic reference.
– H. Georgi, *Lie algebras in particle physics : from isospin to unified theories* (Benjamin, Reading, 1982).