Course: **Physics 701B–Elementary Particles**
Time: Spring 2007, 3:00-4:30 MW, 353 JB (or maybe 042 JB on W)
Instructor: Tom DeLillo, 348 JB, 978-3974(office), 264-7806(home)
Email: delillo@math.twsu.edu
Office hours: 1:00-2:00 ThF, or by appointment
Additional possible meeting times for problems, projects, etc.: W 5-7 PM, MF 10-11 AM

Texts (in library, but you may want to buy at least one):

[Gr1] David Griffiths, *Introduction to Elementary Particles,* (1987) John Wiley & Sons, Inc., ISBN 0-471-60386-4.

[BM] Cliff Burgess and Guy Moore, *The Standard Model: A Primer*, (2007) Cambridge University Press, ISBN 0521860369.

We will attempt to make a transition from the "computational" presentation in [Gr1] (esp. Chs. 3, 6, 7) to the deeper, more up-to-date material in the new text [BM]. Background, mathematical details, and supplementary material will be provided, as needed, from previously used lecture notes and texts [Gr1], [CG], and other references listed below. [BM] is more advanced than [Gr1], [CG], and [HM], but it has some nice explanations of the ideas and is more modern and complete. Time and interest permitting, I will try to give some introductory details on the derivation of the Feynman rules from quantum field theory (QFT), either via a project or via some supplementary lectures; see suggested Project 4, below. (I have strong personal motivations from my own research for making some extra efforts for Projects 4 and 5, below).

Other references for introductory particle physics in our library:

[CG] W. N. Cottingham and D. A. Greenwood, *An Introduction to the Standard Model of Particle Physics,* (1998) Cambridge University Press, ISBN 0-521-58832-4 (pb), I used some of this last time.
[HM] F. Halzen and A. D. Martin, *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, (1984) John Wiley & Sons, ISBN 0-471-88741-2.

You should read [Gr1, Ch. 1 & 2] on your own. Also, it will be helpful to read one of the many popular, nontechnical presentations of particle physics and related ideas in parallel with this course, such as articles from *Scientific American* or, e.g., the book
[Cl] Frank Close, *The New Cosmic Onion: Quarks and the Nature of the Universe*, (2007) Taylor & Francis. I am contemplating offering a nontechnical, honors course on material such as this, perhaps in Spring 2008, to celebrate the start-up of the Large Hadron Collider (LHC).

Additional references for quantum mechanics, special relativity, relativistic quantum mechanics, quantum field theory, and other selected topics:

[AW] G. B. Arfken and H. J. Weber, *Mathematical Methods for Physicists*, Fifth Edition (2001) Academic Press, useful reference for mathematical techniques.
[BD1] J. D. Bjorken and S. D. Drell, *Relatistic Quantum Mechanics*, (1965) McGraw-Hill, a classic, along with companion volume on fields.
[CL] T-P. Cheng and L-F. Li, *Gauge Theory of Elementary Particle Physics*, (1984) Oxford, advanced, starts off with canonical and path integral formalism and ϕ^4.
[Fey] R. P. Feynman, *Statistical Mechanics, A Set of Lectures*, (1972, 1997) Perseus Books, Advanced Book Classics, Addison-Wesley's Frontiers in Physics, we'll use Chap 6 on creation and annihilation operators.
[GJ] J. Glimm and A. Jaffe, *Quantum Physics: A Functional Integral Point of View*, Second Edition, (1987) Springer, advanced mathematical results in constructive QFT.
[GR] W. Greiner and J. Reinhardt, *Field Quantization*, (1996) Springer, one of a series of texts by Greiner et al., contains many details and worked examples.
[Gr2] D. J. Griffiths, *Introduction to Quantum Mechanics*, (1995) Prentice Hall, for QM background.
[Kak] M. Kaku, *Quantum Field Theory, a Modern Introduction,* (1993) Oxford University Press, ISBN, gives overview of QFT and the Standard Model, but many mathematical details are only presented briefly.
[Ma] Michele Maggiore *A Modern Introduction to Quantum Field Theory*, (2005) Oxford U. Press Master Series, this book is meant for advanced undergraduates.
[PS] M. E. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory*, (1995) Perseus Books, a popular QFT text, Chaps 1–4 derive Feynman rules for ϕ^4, Yukawa, and QED interactions, remainder of book treats more QED, path integrals, renormalization, connections to statistical mechanics, and nonAbelian Gauge theories and the standard model.
[RS] M. Reed and B. Simon, *Methods of Modern Mathematical Physics*, vol II, (1975) Academic Press.
[Sm] L. Smolin, *The Trouble with Physics*, (2006) Houghton-Mifflin, criticisms of string theory and overview of alternatives.
[St] C. F. Stevens, *The Six Core Theories of Modern Physics,* (1995) MIT Press, ISBN 0-262-69188-4 (pb), concise presentation without skipping steps, uses path integral formulation of QFT.
[Sto] Michael Stone, *The Physics of Quantum Fields*, (2000) Springer, ISBN 0-387-98909-9, a concise introduction.
[SW] R. Streater and A. S. Wightman, *PCT, Spin, Statistics, and All That*, (1964) Addison-Wesley, see (2000) Princeton U. Press reissue with appendix giving overview of constructive QFT to 1978.
[Zw] Barton Zwiebach, *A First Course in String Theory*, (2004) Cambridge U. Press, the first part contains a detailed presentation of aspects of special relativity, electromagnetism, and classical and quantized (non)relativistic point particles and strings.

Suggested prerequisites: Mainly undergraduate mechanics, special relativity and quantum mechanics, or instructor's consent. Additional physics, such as the Dirac equation and spinors, and mathematics, such as elements of group theory, will be developed as needed.

Grading (approximate)

Homework (keep problem notebook)	100 points
Exam (3/14)	100
Final/Project (times to be arranged)	<u>100</u>
	300 points total

Important dates:

Spring break: 3/19–3/25.
Last day to drop with a "W": 4/2.
Last day of class: 5/7.
Final/Projects: to be arranged.

Brief suggestions for possible (Team or Individual) Projects (to be written up and presented at the end of the semester) in roughly increasing order of difficulty:

Project 1. Symmetries and "zoology" of particles; see [Gr1, Ch. 4], [HM, Ch. 2].

Project 2. Work through the details of the corrections to the spectrum of the hydrogen atom, including the Lamb shift which requires quantization the electromagnetic field; see [Gr1, Ch. 5], [Gr2, Ch. 6], [BD1, Ch. 4], [Ma, p. 74].

Project 3. Selected topics from the texts which we don't have time to cover in class. May be chosen according to interest and background of the students.

Project 4. Work through some details of QFT, e.g., for ϕ^4 theory [PS], [Ma], [CL], [Sto]. QFT provides the theoretical basis for the standard and also for many parts of statistical and condensed matter physics. In spite of it's fundamental role in physics, there are very difficult, unresolved problems in the mathematical foundations of QFT (take a glance at [SW], [GJ], [RS], requires Functional Analysis, Math 941-942 background) and a prize is even available for solving one of them; see http://www.claymath.org/millennium/Yang-Mills_Theory/. I am currently studying some of these topics with Mark Harder.

Project 5. Work through some of Part I of [Zw]. For students taking my Math 758, Complex Variables class, TTh 4-5:15, Spring 2007, you may try to understand the derivation of the Veneziano amplitude for the tree-level scattering of open strings as presented in [Zw, Ch. 23]. The derivation uses the Schwarz-Christoffel transformation for conformal mapping of polygons which will be discussed in Math 758. In the last few years my colleagues, A. Elcrat (WSU) and J. Pfaltzgraff (Chapel Hill) and I, along with D. Crowdy at MIT, have extended the Schwarz-Christoffel formula to multiply connected domains (the complex plane with two or more polygonal holes). It may be possible to use some of the formulas we have developed to study the multiloop amplitudes which contribute higher order terms to the "Feynman series" for string interactions, at least in a special case. String theorists believe this series is finite. However, apparently no proof exists beyond the first few terms; see [Sm, p. 187] on the work of D'Hoker and Phong and others. (I plan to visit Crowdy and Zwiebach at MIT this summer to discuss these matters more fully and will need to study [Zw] more carefully.)

Detailed Syllabus; see [BM], p. xiv.

Part I - Introductory calculations and theoretical framework - about 11 weeks

Week 1, W 1/17, 4 PM, JB 353, organizational meeting, handouts, and brief intro.

Week 2, *Nonrelativistic warm-up*: taken from [Fey, Ch. 6] on creation and annihilation (ladder) operators for (an)harmonic oscillator, fields, Feynman diagrams.

Week 3, *Review of relativistic kinematics*, [Gr1, Ch. 3] and notes.

Week 4 *Feymann rules for a toy model*, [Gr1, Ch. 6] and notes.

Weeks 5, 6, *Quantum electrodynamics*, [Gr2, Ch. 7] and notes.

Weeks 7, 8, [BM, Ch. 1], *Field theory review*, with supplementary material on Lagrangian and Hamiltonian mechanics, symmetries and Noether's Theorem, Lorentz invariance, Dirac algebra, elctromagnetism, etc., as needed see also [Gr1, Ch. 11], Gauge theories.

- 1.1 Hilbert space, creation and annihilation operators
- 1.2 General properties of interactions
- 1.3 Free field theory
- 1.4 Implications of symmetries
- 1.5 Renormalizable interactions
- 1.6 Some illustrative examples

Weeks 9, 10, [BM, Ch. 2], *The standard model: general features*;

- 2.1 Particle content
- 2.2 The Lagrangian
- 2.3 The perturbative spectrum
- 2.4 Interactions

Exam W 3/14

3/19-3/25, *Spring break* - Students should have selected a project by the break.

Week 11, [BM, Ch. 3], *Cross sections and lifetimes*

3.1 Scattering states and the S-matrix
3.2 Time-dependent perturbation theory
3.3 Decay rates and cross sections

Part II - Overviews of selected topics - about Weeks 12-15. If we are not finished with Part I by Week 11, students may want to choose one of the following for a project topic.

[Gr1, Ch. 8-10] on Quantum Chromodynamics (QCD) and Weak Interactions, or, following [BM], p. xiv:

[BM, Ch. 4], *Elementary boson decays*
4.1 Z^0 decay

[BM, Ch. 5], *Leptonic weak interactions: decays*
5.1 Qualitative features
5.2 The calculation
5.3 The large-mass expansion
5.4 Feynman rules

[BM, Ch. 6], *Leptonic weak interactions: collisions*
6.1 The Mandelstam variables
6.2 e^+e^- annihilation: calculation
6.3 e^+e^- annihilation: applications
6.4 The Z boson resonance
6.5 t-channel processes: crossing symmetry
6.6 Interference: Moller scattering
6.7 Processes involving photons

[Bm, Ch. 7], *Effective Lagrangians*
7.1 Physics below M_W: the spectrum
7.2 The Fermi theory

[BM, Ch 8], *Hadrons and QCD*
8.1 Qualitative featurs of the strong interactions

Supplementary lectures/meetings, time permitting, on projects and problems, to be arranged