Collider Phenomenology

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- It is not intended to be broadcasted via internet, though I know that it is being done.
- My lecture notes will be posted on the website (http://www.phy.pku.edu.cn/ qhcao/seminar.html).
- You are encouraged to read the recommended books to help understanding the lecture material.
- You are encouraged to form a working group with 2-3 others in this class to collaborate on project assignments. (Students in experimental HEP group should team up with those in theoretical HEP group, and vice verse.)
- Recommended books:

  1. Barger and Philips, *Collider Physics*
  2. Ellis, Stirling and Webber, *QCD and Collider Physics*
  3. Particle Data Group, *The Review of Particle Physics*

Contents

- Standard Model of Elementary Particle Physics
- Leading Order calculations (with CalcHep and Madgraph, etc.)
- QCD and Parton Distribution Functions (PDFs)
- Next-to-leading order calculations (with MCFM, etc.)
- Regularization, Renormalization, and Running Couplings
- All order calculations (with PYTHIA, HERWIG, ResBos, etc.)
- Experimental Detectors
- Discovery of W and Z bosons
- Discovery of Top quark
- Search for Higgs boson
- Effective Theories at weak scale
- Grand unified theory and proton decay
- Supersymmetry and dark matter candidate
- Technicolor and Extra Dimension models
- The Smoking Gun of New Physics at the LHC

Standard Model of Elementary Particle Physics

- SM is a gauge theory, with local symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y$ to describe strong, weak, and electromagnetic interactions.

- It consists of
  - matter fields
  - force mediators
  - interactions

- How does SM predict? (See the pdf file: How does SM predict.)

Electromagnetic Interaction

- Part of the SM: Quantum Electrodynamics (QED)
- Consider the interaction of electron and photon. (See QED.pdf file.)

Strong Interaction

- Part of the SM: Quantum Chromodynamics (QCD)
- Consider the interaction of quark and gluon
  - Gauge boson kinetic term:

$$-\frac{1}{4}F^{a\mu\nu}F^{a}_{\mu\nu}, \tag{1}$$

where $a = 1 \ldots 8$ are color indices and

$$F^{a\mu\nu} = \partial^{\mu}G^{a\nu} - \partial^{\nu}G^{a\mu} - g_s f^{abc}G^{b\mu}G^{c\nu}. \tag{2}$$

  - Fermion kinetic term and Fermion- gauge boson interaction:

$$\bar{q}_i i\gamma^{\mu}\partial_{\mu}q_i + g_s\bar{q}_i\gamma^{\mu}T^{a}_{ij}q_j G^{a}_{\mu}. \tag{3}$$

  - Gauge-fixing term and Fadeev-Popov ghost term (in 't-Hooft-Feynman gauge):

$$-\frac{1}{2}\left(\partial^{\mu}G^{a}_{\mu}\right)^2 + ig_s f^{abc}\bar{c}^{a}G^{b}_{\mu}\partial^{\mu}c^{c}. \tag{4}$$

Automation Tools

- Create models and generate Feynman Rules
  - LanHEP (http://theory.sinp.msu.ru/∼semenov/lanhep.html)
  - FeynRules (http://feynrules.phys.ucl.ac.be/)
- Parton level Monte Carlo programs
  - CalcHEP (http://theory.sinp.msu.ru/∼pukhov/calchep.html)
  - MadGraph (http://madgraph.hep.uiuc.edu/)

Project-1

- Tabulate the $SU(3)_C$, $SU(2)_L$, $U(1)_Y$, and $U(1)_{em}$ quantum numbers of each field in the Standard Model, including left-handed and right-handed fermion fields, scalar boson field, and gauge boson fields. Find the relation between the electric charge (Q) of a field and its weak isospin (T_{3L}) and hypercharge (Y) quantum numbers.

- Generate the SM Feynman Rules for CalcHEP or MadGraph.