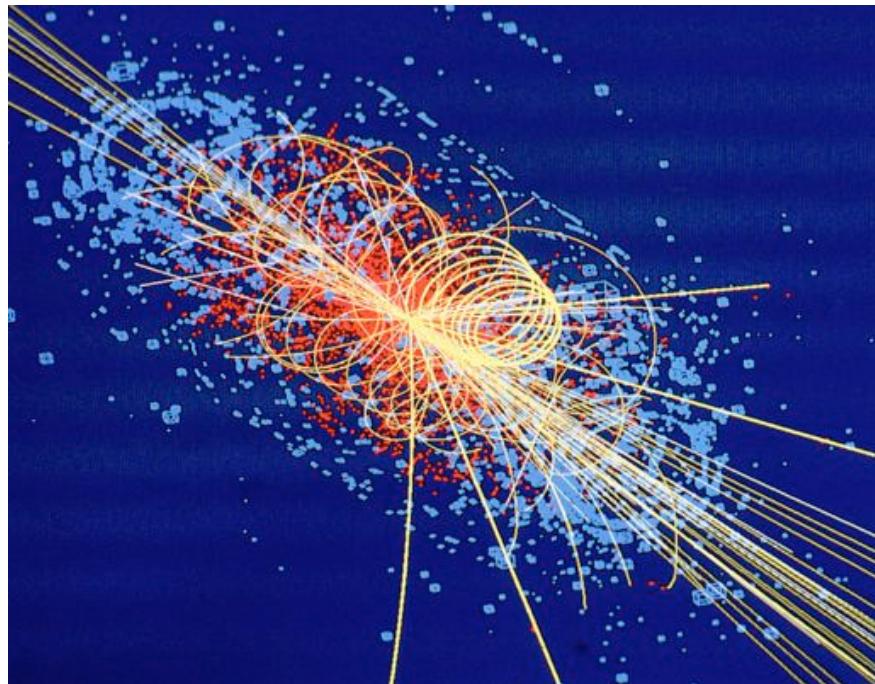


Phenomenology of Particle Physics I

ETH Zurich and University of Zurich

HS 2009



Prof. Dr. Vincenzo Chiochia [UNIVERSITY OF ZURICH]

Prof. Dr. Günther Dissertori [ETH ZURICH]

Prof. Dr. Thomas Gehrman [UNIVERSITY OF ZURICH]

Typeset by Julián Cancino and Julian Schrenk

September 24, 2010

Please feel free to send feedback or error reports to cancinoj@phys.ethz.ch and jschrenk@phys.ethz.ch.

Contents

1	Introduction	1
1.1	Units	2
1.2	Elementary interactions	4
2	Relativistic kinematics	7
2.1	Particle decay	8
2.2	Two-particle scattering	9
2.2.1	Scattering angle	12
2.2.2	Elastic scattering	12
2.2.3	Angular distribution	13
2.2.4	Relative velocity	13
2.2.5	Center of mass and laboratory systems	13
2.3	Crossing symmetry	14
2.3.1	Interpretation of antiparticle-states	15
3	Lorentz invariant scattering cross section	19
3.1	\mathcal{S} -operator	20
3.2	Fermi's golden rule	21
3.2.1	Total decay rate	22
3.2.2	Scattering cross section	23
3.2.3	Invariant phase space for n_f -particles	23
3.2.4	Differential cross section	24
3.3	$2 \rightarrow 2$ scattering cross section	24
3.3.1	Phase space	24
3.3.2	Differential cross section	26
3.4	Unitarity of the \mathcal{S} -operator	26

4 Accelerators and collider experiments	29
4.1 Particle accelerators: motivations	29
4.1.1 Center of mass energy	32
4.2 Acceleration methods	33
4.2.1 Cyclotron	34
4.2.2 Synchrotron	37
4.3 Particle physics experiments	38
4.3.1 Cross section	40
4.3.2 Luminosity	40
4.3.3 Particle detectors	43
4.4 Kinematics and data analysis methods	46
4.4.1 Pseudorapidity and transverse momentum	46
4.4.2 Momentum conservation in particle jets	47
4.4.3 Missing mass method	48
4.4.4 Invariant mass method	51
5 Elements of quantum electrodynamics	55
5.1 Quantum mechanical equations of motion	55
5.2 Solutions of the Dirac equation	59
5.2.1 Free particle at rest	60
5.2.2 Free particle	60
5.2.3 Explicit form of u and v	60
5.2.4 Operators on spinor spaces	61
5.3 Field operator of the Dirac field	65
5.4 Dirac propagator	68
5.4.1 Feynman propagator	69
5.5 Photon field operator	72
5.6 Interaction representation	74
5.6.1 Time evolution operator	75
5.6.2 Time ordering	75
5.7 Scattering matrix	78
5.8 Feynman rules of quantum electrodynamics	80
5.9 Trace techniques for γ -matrices	90

5.10 Annihilation process : $e^+e^- \rightarrow \mu^+\mu^-$	92
5.11 Compton scattering	94
5.12 QED as a gauge theory	98
6 Tests of QED	101
6.1 Measurement of the electron anomalous magnetic moment	101
6.1.1 Electron magnetic moment	101
6.1.2 QED: higher order corrections	102
6.1.3 $g/2$ measurements	103
6.1.3.1 Experiment	103
6.1.3.2 Theoretical predictions	106
6.2 High energy tests	108
6.2.1 e^+e^- colliders	108
6.2.2 Detector elements	110
6.2.3 Cross section measurement	112
6.2.4 Bhabha scattering	113
6.2.5 Lepton pair production	116
6.2.6 Hadronic processes	121
6.2.7 Limits of QED	122
7 Unitary symmetries and QCD as a gauge theory	125
7.1 Isospin $SU(2)$	125
7.1.1 Isospin invariant interactions	129
7.2 Quark model of hadrons	130
7.3 Hadron spectroscopy	131
7.3.1 Quarks and leptons	131
7.3.2 Strangeness	133
7.3.3 Strong vs. weak decays	135
7.3.4 Mesons	136
7.3.5 Gell-Mann-Nishijima formula	136
7.4 Quantum chromodynamics and color $SU(3)$	138
7.4.1 Strength of QCD interaction	145
7.4.2 QCD coupling constant	148

8 QCD in e^+e^- annihilations	153
8.1 The basic process: $e^+e^- \rightarrow q\bar{q}$	155
8.1.1 Singularities	156
8.2 Jets and other observables	159
8.2.1 Jet algorithms	160
8.2.1.1 Examples of jet algorithms	162
8.2.2 Event shape variables	166
8.2.3 Applications	172
8.3 Measurements of the strong coupling constant	179
8.4 Measurements of the QCD color factors	190
8.5 Hadronization	191