

Index

- $O(\dots)$, 592
- S_ϵ , 590
- Γ , 591
- $\Theta(\dots)$, 593
- $\epsilon_{\kappa\lambda\mu\nu}$, 584
- ϵ_{ij} , 584
- $\stackrel{?}{=}$, 582
- $\stackrel{\text{def}}{=}$, 582
- $\stackrel{\text{prelim}}{=}$, 582
- π^0 decay, 16, 30
- \sim , 594
- $g_{\mu\nu}$, 584, 595
- $o(\dots)$, 593
- abbreviations, *see* Sec. A.3
- ACOT, 64–67, 307, 414
- acronyms, *see* Sec. A.3
- active quark, 414
- Altarelli-Parisi equation, *see* DGLAP equation
- angular coordinate, 130, 315, 321
- anomalous dimension, 53, 584
- anomaly, 16, 30, 61
- antiquark density, 232
- approximant, *see* approximator
- approximator, 163–165, 248–249, 272, 563
 - e^+e^- annihilation, 449–451, 485–488
 - example, 320–321
 - region, 313, 317, 321, 345–351
 - SIDIS, 531
 - Sudakov, 323–329
- asymptotic behavior
 - general formulation, 131–134
 - and pinch-singular surfaces, 90
- asymptotic freedom, 24, 28, 53, 55
- asymptotic series, 581
- averaged cross section, 70–75, 84–86, 96, 400, 428, 455, 469, 487, 544
- axial anomaly, *see* anomaly
- axial gauge, 118, 394, 444, 572
 - and CSS evolution, 379, 396
 - and factorization proofs, 446, 561
 - power-counting, and, 135
- b_1 , *see* DIS deuterium
- bad components, 181
- bare coupling, 9, 37, 58
- bare parton density, 252, 257, 263, 309
- bare quantities, 9
- baryon, 12
- basic interaction Lagrangian, 41
- Bessel transform, 538, 568
- BFKL, 575–576
- Bjorken scaling, 26, 28, 29
- Bjorken sum rule, 199
- Bjorken variable, 19, 25, 427
- Bloch vector, 586
 - and massless particles, 588
- Boer-Mulders function, 533, 535, 569
- boost, 596
- breakable string, *see* string model
- Breit frame, 22
- brick-wall frame, 22
- BRST transformation, 38, 417–418
 - renormalized, 40
- Cabibbo-Kobayashi-Maskawa mixing matrix, *see* CKM matrix
- Callan-Gross relation, 28, 433
- CCFM equation, 576
- CERN, 2
- chiral symmetry, *see also* helicity conservation, 15, 61
 - hard scattering, 61
- CKM matrix, 32, 214
- collinear factor, 369, 372, 379, 389, 491
 - unsubtracted, 360
- collinear factorization
 - defined, 479
 - v. TMD factorization, 479
- collinear momentum
 - characterization, 325
- collinear subgraph, *see also* factorization, *see also* pinch-singular surface, 326, 451
 - definition, 93
 - power-counting, 113, 116–118, 142–144
- Collins function, 493, 533

- Collins-Soper evolution, 374–378, 383
 - calculation, 388, 504
 - flavor dependence, 502
 - fragmentation function, 501–502
 - kernel, 388, 504
 - non-perturbative, 506–507
 - parton density, 529
 - renormalization group, 384
 - Sudakov, 374–378, 384
- Collins-Soper frame, 543
- color, 9, 10, 12, 16, 30
- contour deformation, *see also* Glauber region, 110–111
- contravariant vector, 584, 596
- conventions, 584–585
 - states, 587, 590
- conversion factors, 582
- Coulomb gauge, 394, 572
 - and CSS evolution, 379, 396
 - and factorization proofs, 446, 561
 - power-counting, and, 135
- Coulomb region, *see* Glauber region
- counterterm
 - Feynman rules, 44
 - Lagrangian, 41, 42
- covariant derivative, 9, 31
- covariant vector, 584, 596
- critique of conventional treatments of factorization, 307–309
- cross section
 - general formula, 587
- current algebra, 10, 13, 15, 35
- current fragmentation, 473
- cut diagram definition, 21
- CWZ, 64–67, 307, 414
- DDVCS, 102, 415–416, 574
 - reduced graph, 101
- decoupling theorem, 413
- deeply inelastic scattering, *see* DIS
- deeply virtual Compton scattering, *see* DVCS
- density matrix, 585
- DGLAP equation, 2, 5
 - calculations of kernel, 286–293
 - fragmentation function, 431
 - parton density, 261–262, 411–412
 - QCD, 411–412
 - results for kernel, 288, 293, 464
 - sum rule, 263–264
- diffractive
 - DIS, 477
 - parton density, 477
 - scattering, 574
- dimensional regularization, 589–591
- dimensional transmutation, 56
- Dirac matrix, 587–588
 - projector, 164, 329, 487
- DIS, *see also* parton model
 - charged current, 213–217
- cross section formula, 20
- data, 27
- deuterium, 211, 283
- diffractive, 477
- event picture, 19, 98
- factorization, 276–280, 404–411
- hadronic tensor, 21
- hadronization in, 24
- handbag graph, 25, 161, 237, 269, 316
- heavy quarks, 306–307, 413
- kinematics, 19
- known calculations, 309
- large x , 400, 579
- leading region, 96, 147
- masses, effects of, 306–307, 413
- NLO
 - gluon coefficient, 296
 - quark coefficient, 301
- NLO in QCD, 284–312
- parton model for, 23
- phenomenology, 310–312
- polarized, in parton model, 168
- polarized, in QCD, 278, 412
- projection onto structure functions, 285
- QCD, 398–425
 - reduced graph, 95–100
- regions, 399–404
- scalar exchange, 35
- scalar quark, 35
- small x , 575
- spin-1, 211, 283
- structure function, 22, 214
 - general, 214
- structure functions in parton model, 26, 168, 215
- uncut amplitude, 95–99, 399
- weak interaction, 213–217, 412
- dispersion relation, 85
- Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equation, *see* DGLAP equation
- double deeply virtual Compton scattering, *see* DVCS
- Drell-Yan process, 3, 103–105, 540–569
 - data, 564–568
 - factorization, 553–562
 - factorization statement, 4, 541
 - Glauber region, 545–553, 556–560
 - leading region, 103, 544
 - polarization, 281, 568
 - power-counting, 136
 - reduced graph, 103–105
 - TMD factorization, 560, 562–569
- duality, *see* parton-hadron duality
- DVCS, 102, 415–416, 574
 - leading region, 102
 - reduced graph, 101
- e^+e^- annihilation
 - back-to-back region, 467
 - Glauber region, 445

- jet cross sections, 469
- LO calculation, 76, 495
- multiparticle cross sections, 466
- multiparticle fragmentation, 468
- NLO calculation, 75–81
- one-particle inclusive, 426–433, 439–461
 - cross section, 428
 - factorization, 429–432, 448–461
 - hadronic tensor, 427
 - leading region, 439
 - LO, 432
 - NLO, 464–465
 - structure function, 428
- total cross section, 69–86
 - results, 80
- two-particle inclusive, 479–501, 514–519
 - hadronic tensor, 484
 - leading region, 480
 - structure function, 484
- TMD factorization, 494, 496–501
- effective coupling, 55
- elastic scattering at wide angle, 574
 - Landshoff process, 147–148
 - leading regions, 147–148
- elastic spring, 82, 426
- equality signs, 7, 582
- equation-of-motion operator, 410
- event picture, 19, 98
- evolution of final state, 81–84
- exclusive diffraction, 574
- exclusive scattering, *see also* DDVCS, *see also*
 - diffractive scattering, *see also* DVCS, *see also*
 - elastic scattering
- extended fracture function, 476
- extended leading order approximation, 273
- F_1, F_2, F_2, F_L , *see* DIS structure function
- factorization, 4, 243–283
 - critique of conventional treatments, 307–309
 - DIS, 404–411
 - Drell-Yan, 553–562
 - e^+e^- annihilation
 - one-particle inclusive, 429–432, 448–461
 - two-particle inclusive, 494, 496
 - elementary treatment, 245–251
 - gauge theory, 405–411
 - general methods, 313–397
 - initial-state partons, 569
 - masses, effects of, 306–307, 413
 - NLO calculations, 284–312
 - non-abelian gauge theory, 407–411
 - on-shell partons, 285
 - parton model, 167–168
 - polarized, 280–282
 - SIDIS, 475, 526–537
 - subtractions, 314–319
 - successive approximation method, 269–271
- Sudakov form factor, 359–374, 378–388
- TMD, *see* TMD factorization
- factorization scale, *see* renormalization scale
- Faddeev-Popov gauge fixing, 37
- Faddeev-Popov ghost, 37, 228
- Feynman parameter, 592
- Feynman rules
 - fragmentation function, 460
 - parton density, 201–202, 235–237
 - QCD, 43, 44
 - Wilson line, 236
- final state in fragmentation, 460
- final-state interaction, 170, 545–552
- flavor, 9, 12, 16, 30
- flavor relations
 - fragmentation function, 438
 - parton density, 195–201
- flavor SU(3), 60
- Fourier transform, 591
- fracture function, 475–477
- fragmentation function, 429, 430
 - antiquark, 437
 - basic definition, 435–438
 - definition, 459
 - definition (TMD), 498, 529
 - DGLAP equation, 431, 464
 - Feynman rules, 460
 - final state, 460
 - flavor relations, 438
 - introduction, 433–439
 - isospin, 438
 - moment, 431
 - momentum sum rule, 438
 - multiparticle, 468
 - polarized, 437
 - positivity, 493
 - QCD, 459
 - quark, 436
 - renormalization, 431, 437, 461–464, 499
 - renormalization group, 431, 502
 - scalar, 435
 - sum rule, 438
 - TMD, 436, 492, 498
 - evolution, 501–502
 - final definition, 498
 - non-perturbative part, 510
 - polarized quark, 491
 - quark, 491
 - relation to integrated f.f., 496, 507–512, 519–526
 - renormalization, 499
 - renormalization group, 502
 - transverse-momentum dependent, *see*
 - fragmentation function, TMD
 - unintegrated, *see* fragmentation function, TMD
 - frame dependence of time ordering, 225, 552
 - Froissart bound, 548, 576
 - functional integral, 36

- G* gluon, *see* Grammer-Yennie
- g_1, g_2 , *see* DIS structure function
- Gamma function, 591
- gauge fixing, 37
- gauge link, *see* Wilson line
- gauge transformation, *see also* BRST transformation, 9, 38
 - Wilson line, 230
- generalized parton density, 193, 416, 575
- generation, 31
- Glauber region
 - and axial gauge, 395, 445
 - basics, 122–125
 - DIS, 125
 - Drell-Yan, 126–128, 156–158, 545–554, 556–560
 - e^+e^- annihilation, 125, 445
 - general determination, 125–130, 156–158
 - power-counting, 128, 150
 - SIDIS, 474, 528
 - space-time interpretation, 125, 126, 551
 - Sudakov, 331, 348–350
- gluon, 9
 - polarization, 242
- gluon density, 232–235
- Goldberger-Treiman relation, 15
- good components, 181
- GPD, *see* generalized parton density
- Grammer-Yennie method, 118, 122, 123, 143, 328, 345, 347, 402, 560
 - G* gluon, 402, 422
 - K* gluon, 402, 404–406, 416–425, 488
- grand unified theories, 32
- Green function and S matrix, 34
- group theory, 588
- hadron, 1, 10, 12
- hadron frame, 434, 481, 483, 527, 530, 543, 563
- hadron production in hadron-hadron collisions, 542, 570
- hadronic tensor
 - DIS, 21
 - Drell-Yan process, 543
 - e^+e^- annihilation one-particle inclusive, 427
 - e^+e^- annihilation, two-particle inclusive, 484
 - factorization, 276
 - SIDIS, 530
- hadronization, 24
- handbag graph, 25, 161, 237, 269, 316
- hard factor, 361, 373, 382, 391, 422
- hard pomeron, 576
- hard scattering, multiple, 147–148
- hard subgraph, *see also* factorization, *see also* pinch-singular surface, 327, 329, 417, 451
 - definition, 93
 - power-counting, 112, 141
- heavy-quark effective theory, 579
- heavy quarks, 62, 64–67, 76, 214–217, 306–307, 327, 413, 569, 578
- helicity, 585
- helicity conservation, 169, 281
- helicity density, 166, 176, 189, 202, 234
- hierarchy, *see* region hierarchy
- Higgs, 2, 14, 31, 103, 160, 543, 577
- higher twist, 580
- Hopf algebra, 313
- inactive quark, 414
- infinite-momentum frame, 180, 217
- infra-red safety, 69, 469
- initial-state interaction, 561, 581
- integrated fragmentation function, *see* fragmentation function
- integrated parton density, *see* parton density
- intermediate state, 217, 218, 221
- intrinsic coordinate, 130, 133, 315, 321
- intrinsic transverse momentum, 510
- isospin, 60
 - fragmentation function, 438
 - parton density, 195–199
- jet cross sections, 469
- jet factor, 167
- jet shapes, 576
- K* gluon, *see* Grammer-Yennie
- kinematic zero, 485
- Kinoshita-Lee-Nauenberg theorem, *see* KLN theorem
- KLN theorem, 69, 443
- k_T factorization, *see* TMD factorization
- ladder graphs, 546, 578
- ladder method, 256–261, 271–276
- Lagrangian
 - QCD, 9, 37
- Landau criterion, 91, 110
 - coordinate space, 159
 - Glauber region, 128
 - proof, 159
- Landshoff process, 147–148, 574
- large N , 83
- large x , 172, 400, 579
- lattice QCD, 1, 38
- leading region, *see* region
- leading-logarithm approximation, *see* LLA
- lepton, 14
- LHC, 2, 577
- Libby-Sterman method, 87–160
 - Glauber region, 128, 157
- light-cone gauge, 228, 230, 245, 285, 411
- light-front coordinates, 584, 595–599
 - parton model, 23
- light-front perturbation theory, 217–225
 - derivation, 222–223
 - fermion line, 223
 - gauge theory, 229
 - gluon line, 229

- QCD, 229
- rules, 221–224
- light-front quantization, *see also* light-front perturbation theory, 180–185, 573
- fragmentation function, 435
- in gauge theory, 227–229
- paradox, 219–221
- parton density, 185–189
- QCD, 227–229
- renormalization, 198
- vacuum, 219
- wave function, 225–227, 574
- zero mode, 182, 219
- light-front wave function, 225–227, 574
- linear polarization, 234, 242
- LLA, 332, 387, 517–518
- Lorentz covariance of parton density, 191
- Lorentz group, 585
- low-energy effective theory, 63
- LSZ reduction, 79, 204
- mass divergences, 87
- masses of elementary fields in Standard Model, 32
- Mellin transform, 262–263
- meson, 12
- metric tensor, 584, 596
- minimal subtraction, *see* $\overline{\text{MS}}$ scheme
- mixing angle, Weinberg, 32
- mixing matrix, neutrino, *see* MNS
- mixing matrix, quark, *see* CKM
- MNS matrix, 32
- Monte-Carlo event generators, 577–578
- $\overline{\text{MS}}$ scheme definition, 43–45, 590
- multi-peripheral model, 546
- multiple hard scattering, 147–148
- Nachtmann variable, 25
- neutron decay, 14
- non-abelian gauge theory, 9, 16
- non-leading logarithms, 393
- non-perturbative
 - Collins-Soper evolution, 506–507
 - interactions and fragmentation, 465
 - TMD fragmentation function, 510
 - TMD parton density, 564
- normal coordinate, 130, 133
- notation, 6, 582–594
 - orders of magnitude, 592–594
- OPE, *see* operator product expansion
- operator product expansion, 28, 200, 251, 263, 283, 313, 321, 408, 409, 411, 580
- optimization of perturbation theory, *see* scale choice ordering
 - partial, 316
 - total, 316, 352
- overlapping divergence, 352
- partial ordering, 316
- particle-field relation, 33
- parton, *see also* DIS, *see also* parton density, *see also* parton model, 23
 - basics, 2, 4
- parton density, 4, 24
 - in antiproton, 196
 - antiquark, 175, 232
 - bare, 252, 257, 263, 309
 - Boer-Mulders, 533
 - definition (integrated), 165–167, 174–177, 201–202, 232–235
 - DGLAP equation, 261–262
 - diffractive, 477
 - example calculations, 202–210, 264–268, 286–293
- Feynman rules
 - basic, 201–202
 - QCD, 235–237
- flavor relations, 195–201
- in gauge theory, 229–235, 529
- gauge invariant, 232–235
- gluon, 196, 232–235, 242
- integrated v. unintegrated, 186
- isospin, 195–199
- Lorentz covariance, 191
- Mellin transform, 262–263
- moment, 200, 262–263
- momentum sum rule, 194, 197
- negative x , 175, 176, 191–192, 208–210
- in nucleus, 196
- number density, 185–189
- number sum rule, 194, 197
- operator definition, 174–177, 192–193, 232–235, 529
- in pion, 197, 235
- polarized, 165–167, 176–180, 189, 233–235, 242, 253, 533
- positivity, 190
- pretzelosity, 533
- QCD, 229–237, 529
- quark, 174, 232, 529
- renormalization, 198–199, 205, 251–261, 264–268, 286–293, 411–412, 529
- renormalization group, 261–262, 530
- scalar, 210
- Sivers, 533
- sum rule, 194, 197, 199, 206–207, 263–264
- support, 176, 191
- TMD, 190, 282, 529
 - final definition, 529
 - non-perturbative part, 564
 - polarized, 532
 - relation to integrated density, 294, 529–530
 - renormalization, 529
 - renormalization group, 530
- transverse-momentum dependent, *see* parton density, TMD

- parton density (*cont.*)
 - uncut, 207–208
 - unintegrated, *see* parton density, TMD
 - universality, *see* universality
 - UV divergence, 205, 253
- parton distribution function, *see* parton density
- parton frame, 434
- parton model, 20, 87
 - approximator, 163–165, 248–249, 272
 - compared with reality, 96, 97
 - factorization, 167–168
 - for DIS, 23
 - gauge invariant, 237–241
 - heavy quarks, 215–217
 - polarization, 167, 168
 - SIDIS, 471
 - theory of, 161–212
 - validity, 170–173
- parton-hadron duality, 401
- Pauli-Lubański vector, 585
- perturbation theory
 - optimization, *see* scale choice
 - validity, 75
- photon frame, 481, 482, 527, 531, 543, 563
- pinch-singular surface, *see also* region
 - angular coordinate, 130, 315
 - basics, 89–91
 - coordinates, 130–134
 - definition, 87
 - geometry, 106–108
 - intrinsic coordinate, 130, 133, 315
 - non-pinch comparison, 108–111
 - normal coordinate, 130, 133
 - radial coordinate, 113, 118, 119, 121, 130, 133–134, 315
 - region specified by, 315
 - skeleton, 88, 315
 - topology, 106–108
- plus distribution, 292, 524, 591–592
- polarization, *see also* fragmentation function
 - polarized, *see also* parton density polarized, 165, 177–180, 233–235, 585–586
 - DIS, 168, 278, 412
 - Drell-Yan process, 281, 568
 - linear, 234, 242
 - SIDIS, 532
 - polarized DIS, 279
 - pomeron, 546, 576
 - positivity, 190, 493, 525
 - power corrections, 580
 - power-counting, 134–145
 - alternate scalings, 144
 - collinear subgraph, 113, 116–118, 142–144
 - dimensional analysis, comparison, 135, 141
 - gauge theory, 117
 - general form, 140–145
 - Glauber region, 128, 150
- hard subgraph, 141
- multiple/nested regions, 148–156
- soft subgraph, 119–122, 144
- Sudakov form factor, 111–125
- super-renormalizable couplings, 140, 146
- pretzelosity, 533
- proton radius, 11
- pseudo-rapidity, 598
- PSS, *see* pinch-singular surface
- QCD
 - Λ , 55–56
 - definition, 9
 - Feynman rules, 43, 44
 - gauge transformation, 9
 - history, 10
 - justification, 6, 10, 29
 - Lagrangian, 9, 37
 - predictive power, 2, 311
 - renormalization, 39–48
 - renormalization group, 51–59
 - renormalization-group coefficients, 58
 - scale parameter, 55–56
 - symmetries, 60–61
- quark
 - charges, 32
 - masses, 32
 - quark density, 232
 - quark model, 12
 - quark-parton model, *see* parton model
 - quark-quark potential, 34
- radial coordinate, 113, 118, 119, 121, 130, 133–134, 315, 321
- rapidity, 584, 596–598
- rapidity divergence, 291, 338, 339, 342, 343, 348, 350, 351, 361, 379, 382, 407, 522–524, 536
- rapidity gap, 5
- reduced graph, 91
 - coordinate space, *see* reduced graph space-time
 - DDVCS, 101–102
 - DIS, 95–100
 - Drell-Yan, 103–105
 - DVCS, 101–102
 - examples, 106
 - interpretation, 106–108
 - space-time, 91–92, 106, 108, 116, 121–122, 125, 148, 152, 158, 159, 551
 - Sudakov form factor, 92–95
 - Regge physics, 574, 575
 - reggeon, 546
- region, *see also* pinch-singular surface
 - approximator, 323–329
 - decomposition, 246–247, 314, 351
 - e^+e^- annihilation, 485
 - hierarchy, 108, 130, 315–317, 323, 366–369
 - power-counting effects, 149–156
 - leading, 315, 401

- DIS, 96, 147
- Drell-Yan, 103, 544
- DVCS, 102
- e^+e^- annihilation, one-particle inclusive, 439
- e^+e^- annihilation, two-particle inclusive, 480
- elastic scattering at wide angle, 147–148
- gauge theory, 245
- general criteria, 146–148
- non-gauge theory, 244
- rule for, 147
- SIDIS, 472, 528
- Sudakov form factor, 94
- minimal, 316, 317
- multiple, 148
- nested, 148, 316
- pinch-singular surface, comparison with, 135
- properties, 316
- soft quark, 125
- space-time interpretation, 99, 551
- superleading, 144, 315, 401, 440
- terminology, 315
- remnant-remnant interactions, 126, 545–552, 554–560
- renormalization, *see also* fragmentation function
 - renormalization, *see also* parton density
 - renormalization
- BRST transformation, 40
- by subtraction of asymptote, 48–51, 293–295, 299
- fragmentation function, 431
- $\overline{\text{MS}}$, *see* $\overline{\text{MS}}$ scheme; ACOT; CWZ
- parton density, 251
- QCD, 39–45
- region approximator, 329
- wave function, 40
- renormalization group, *see also* DGLAP equation, 28, 45, 51, 59, 579
 - conventions, 584
 - fragmentation function, 431
 - parton density, 261
 - TMD fragmentation function, 502
 - TMD parton density, 530
- renormalization scale, 44, 300–301, 516
 - meaning, 48–51
- resummation, 518–519, 576
- running coupling, *see* effective coupling
- scalar polarized gluon, *see also* Grammer-Yennie method K gluon, 141, 143, 146, 147
- scale choice, 48–51, 300–301, 516
- scale dependence, *see* renormalization group; DGLAP equation
- SCET, *see* soft-collinear effective theory
- semi-inclusive deeply inelastic scattering, *see* SIDIS
- short-distance dominance, 75, 84
- SIDIS, 470–475
 - factorization, 475
 - Glauber region, 474, 528
 - hadronic tensor, 530
 - leading region, 472, 528
- polarization, 532
- structure function, 532
- target-fragmentation region, 475–477
- TMD factorization, 526–537
 - final form, 532
- Sivers function, 533, 534
- skeleton of pinch-singular surface, 88, 315
- Slavnov-Taylor identity, *see also* Ward identity, 407, 418, 421
- small x , 575
- soft cancellation, 456
- soft factor, 359, 366
- soft quark region, 125
- soft subgraph, *see also* factorization, *see also* pinch-singular surface, 326, 452
 - definition, 93
 - power-counting, 119–122, 144
- soft-collinear effective theory, 579
- soft-collinear gluons, 327, 354
- space-time propagation, *see also* reduced graph, 91–92, 99, 106, 108, 116, 121–122, 125, 126, 148, 152, 224, 551, 573
- spectator-spectator interactions, 126
- spin projection, 588
- spin vector, 586
- spontaneous symmetry breaking, 61
- Standard Model, 31, 33
 - masses of particles, 32
 - quantum numbers, 32
- string model, 88, 426
- strong $C\,P$ problem, 60
- structure-function
 - DIS, 22, 214
 - general, 214
 - e^+e^- annihilation
 - one-particle inclusive, 428
 - two-particle inclusive, 484
 - factorization, 276–280
 - longitudinal, 22
 - parton-density comparison, 169
 - summary, 586
 - transverse, 22
 - subtraction method, 258–261, 314–319
 - example, 320–321
- successive approximation method, 269–271, 314
- Sudakov form factor, 321–344, 359–397
 - calculations, 330–344, 388–393
 - definition, 88
 - factorization, 322, 374, 378–388
 - final solution, 383–387
 - large Q asymptote, 387
 - leading region, 94
 - non-leading logarithms, 393
 - one loop, 105–125, 330–344
 - regions, 323
 - regions at two-loop order, 153
 - sum-over-cuts, 441, 443, 447–448, 456–459, 475, 548

- sum rule, *see* fragmentation function, *see* parton density
super-renormalizable couplings, 140, 146
superleading region, *see* region, superleading
supersymmetry, 2, 32, 37, 160, 503
target fragmentation, 473, 475–477
test function, *see* averaged cross section
three-particle phase space, 590
time-ordered perturbation theory, 217, 447
time-reversal transformation
 and Drell-Yan, 554
 and TMD fragmentation, 536
TMD factorization, 479–537
 combining with collinear factorization, 501, 513
 defined, 479
 Drell-Yan, 560, 562–569
 e^+e^- annihilation, 496–501
 SIDIS, 526–537
 using, 514–519
 v. collinear factorization, 479
TMD fragmentation function, *see* fragmentation function, TMD
TMD parton density, *see* parton density, TMD
total ordering, 316, 352
transverse coordinate space, 495
transverse mass, 597
transverse spin, 166, 169, 280–282
transverse-momentum dependent fragmentation function, *see* fragmentation function, TMD
transverse-momentum dependent parton density, *see* parton density, TMD
transversity density, 166, 176, 189, 202, 281
twist, 580
two-particle phase space, 590
unbreakable elastic spring, 82
uniformity, 594
unintegrated fragmentation function, *see* fragmentation function, TMD
unintegrated parton density, *see* parton density, TMD
unit of mass, *see* renormalization scale
units, 582
universality
 modified, 535
 parton density, 2, 6
vertex graph, *see* Sudakov form factor
W boson, 14, 31, 32
Ward identity, 346, 362, 407, 416–425, 488,
 578
 with subtractions, 367
wave packet, 71–75, 187–189
wave-function renormalization, 40
weak interaction, 14
Weinberg angle, 32
Weinberg-Salam theory, 10, 14, 16, 29
Wilson line, 230–232, 361, 410–411
 BFKL, 575
 evolution, 343, 374–378, 383
Feynman rules, 236
 in fragmentation function, 459
 gauge transformation, 230
 interpretation, 237–241
 in parton density, 232
 path dependence, 230–232
 rapidity, 343
 self-interaction, 360, 365, 379, 380, 491,
 499–500
 in soft factor, 489, 497
 in TMD fragmentation function, 497–499
 in TMD parton density, 529
Yang-Mills theory, 9, 16
Yukawa coupling, 31
Yukawa theory, 180, 202, 226, 264
Z boson, 14, 32
zero mode, 182, 219