30. MONTE CARLO PARTICLE NUMBERING SCHEME

Revised April 2000 by L. Garren (Fermilab), I.G. Knowles (Edinburgh U.), T. Sjöstrand (Lund U.), and T. Trippe (LBNL).

The Monte Carlo particle numbering scheme presented here is intended to facilitate interfacing between event generators, detector simulators, and analysis packages used in particle physics. The numbering scheme was introduced in 1988 [1] and a revised version [2,3] was adopted in 1998 in order to allow systematic inclusion of quark model states which are as yet undiscovered and hypothetical particles such as SUSY particles. The numbering scheme is used in several event generators, *e.g.* HERWIG and PYTHIA/JETSET, and in the `/HEPEVT/` [4] standard interface.

The general form is a 7–digit number:

$$\pm n \, n_r \, n_L \, n_{q_1} \, n_{q_2} \, n_{q_3} \, n_J \ .$$

This encodes information about the particle's spin, flavor content, and internal quantum numbers. The details are as follows:

1. Particles are given positive numbers, antiparticles negative numbers. The PDG convention for mesons is used, so that K^+ and B^+ are particles.
2. Quarks and leptons are numbered consecutively starting from 1 and 11 respectively; to do this they are first ordered by family and within families by weak isospin.
3. In composite quark systems (diquarks, mesons, and baryons) $n_{q_{1-3}}$ are quark numbers used to specify the quark content, while the rightmost digit $n_J = 2J + 1$ gives the system's spin (except for the K^0_S and K^0_L). The scheme does not cover particles of spin $J > 4$.
4. Diquarks have 4-digit numbers with $n_{q_1} \geq n_{q_2}$ and $n_{q_3} = 0$.
5. The numbering of mesons is guided by the nonrelativistic (L–S decoupled) quark model, as listed in Table 13.2.
   a. The numbers specifying the meson's quark content conform to the convention $n_{q_1} = 0$ and $n_{q_2} \geq n_{q_3}$. The special case K^0_L is the sole exception to this rule.
   b. The quark numbers of flavorless, light (u, d, s) mesons are: 11 for the member of the isotriplet ($\pi^0, \rho^0, \ldots$), 22 for the lighter isosinglet ($\eta, \omega, \ldots$), and 33 for the heavier isosinglet ($\eta', \phi, \ldots$). Since isosinglet mesons are often large mixtures of $u\overline{u} + d\overline{d}$ and $s\overline{s}$ states, 22 and 33 are assigned by mass and do not necessarily specify the dominant quark composition.
   c. The special numbers 310 and 130 are given to the K^0_S and K^0_L respectively.
   d. The fifth digit n_L is reserved to distinguish mesons of the same total (J) but different spin (S) and orbital (L) angular momentum quantum numbers. For $J > 0$ the numbers are: $(L, S) = (J-1, 1)$ $n_L = 0$, $(J, 0)$ $n_L = 1$, $(J, 1)$ $n_L = 2$ and $(J+1, 1)$ $n_L = 3$. For the exceptional case $J = 0$ the numbers are $(0, 0)$ $n_L = 0$ and $(1, 1)$ $n_L = 1$ (*i.e.* $n_L = L$). See Table 30.1.
   e. If a set of physical mesons correspond to a (non-negligible) mixture of basis states, differing in their internal quantum numbers, then the lightest physical state gets the smallest basis state number. For example the $K_1(1270)$ is numbered 10313 (1^1P_1 K_{1B}) and the $K_1(1400)$ is numbered 20313 (1^3P_1 K_{1A}).
   f. The sixth digit n_r is used to label mesons radially excited above the ground state.
   g. Numbers have been assigned for complete $n_r = 0$ S- and P-wave multiplets, even where states remain to be identified.

Table 30.1: Meson numbering logic. Here qq stands for $n_{q2}\, n_{q3}$.

	$L = J - 1,\, S = 1$			$L = J,\, S = 0$			$L = J,\, S = 1$			$L = J + 1,\, S = 1$		
J	code	J^{PC}	L	code	J^{PC}	L	code	J^{PC}	L	code	J^{PC}	L
0	—	—	—	$00qq1$	0^{-+}	0	—	—	—	$10qq1$	0^{++}	1
1	$00qq3$	1^{--}	0	$10qq3$	1^{+-}	1	$20qq3$	1^{++}	1	$30qq3$	1^{--}	2
2	$00qq5$	2^{++}	1	$10qq5$	2^{-+}	2	$20qq5$	2^{--}	2	$30qq5$	2^{++}	3
3	$00qq7$	3^{--}	2	$10qq7$	3^{+-}	3	$20qq7$	3^{++}	3	$30qq7$	3^{--}	4
4	$00qq9$	4^{++}	3	$10qq9$	4^{-+}	4	$20qq9$	4^{--}	4	$30qq9$	4^{++}	5

h. In some instances assignments within the $q\bar{q}$ meson model are only tentative; here best guess assignments are made.

i. Many states appearing in the Meson Listings are not yet assigned within the $q\bar{q}$ model. Here $n_{q_{2-3}}$ and n_J are assigned according to the state's likely flavors and spin; all such unassigned light isoscalar states are given the flavor code 22. Within these groups $n_L = 0, 1, 2, \ldots$ is used to distinguish states of increasing mass. These states are flagged using $n = 9$. It is to be expected that these numbers will evolve as the nature of the states are elucidated.

6. The numbering of baryons is again guided by the nonrelativistic quark model, see Table 13.4.

   a. The numbers specifying a baryon's quark content are such that in general $n_{q_1} \geq n_{q_2} \geq n_{q_3}$.

   b. Two states exist for $J = 1/2$ baryons containing 3 different types of quarks. In the lighter baryon ($\Lambda, \Xi, \Omega, \ldots$) the light quarks are in an antisymmetric ($J = 0$) state while for the heavier baryon ($\Sigma^0, \Xi', \Omega', \ldots$) they are in a symmetric ($J = 1$) state. In this situation n_{q_2} and n_{q_3} are reversed for the lighter state, so that the smaller number corresponds to the lighter baryon.

   c. At present most Monte Carlos do not include excited baryons and no systematic scheme has been developed to denote them, though one is foreseen. In the meantime, use of the PDG 96 [5] numbers for excited baryons is recommended.

7. The gluon, when considered as a gauge boson, has official number 21. In codes for glueballs, however, 9 is used to allow a notation in close analogy with that of hadrons.
8. The pomeron and odderon trajectories and a generic reggeon trajectory of states in QCD are assigned codes 990, 9990, and 110 respectively, where the final 0 indicates the indeterminate nature of the spin, and the other digits reflect the expected "valence" flavor content. We do not attempt a complete classification of all reggeon trajectories, since there is currently no need to distinguish a specific such trajectory from its lowest-lying member.
9. Two-digit numbers in the range 21–30 are provided for the Standard Model gauge bosons and Higgs.
10. Codes 81–100 are reserved for generator-specific pseudoparticles and concepts.
11. The search for physics beyond the Standard Model is an active area, so these codes are also standardized as far as possible.

    a. A standard fourth generation of fermions is included by analogy with the first three.

b. The graviton and the boson content of a two-Higgs-doublet scenario and of additional SU(2)×U(1) groups are found in the range 31–40.
c. "One-of-a-kind" exotic particles are assigned numbers in the range 41–80.
d. Fundamental supersymmetric particles are identified by adding a nonzero n to the particle number. The superpartner of a boson or a left-handed fermion has $n = 1$ while the superpartner of a right-handed fermion has $n = 2$. When mixing occurs, such as between the winos and charged Higgsinos to give charginos, or between left and right sfermions, the lighter physical state is given the smaller basis state number.
e. Technicolor states have $n = 3$. In the absence of a unique theory we only number generic states whose digits reflect the techniquark content.
f. Excited (composite) quarks and leptons are identified by setting $n = 4$.

12. Occasionally program authors add their own states. To avoid confusion, these should be flagged by setting $nn_r = 99$.
13. Concerning the non-99 numbers, it may be noted that only quarks, excited quarks, squarks, and diquarks have $n_{q3} = 0$; only diquarks, baryons, and the odderon have $n_{q_1} \neq 0$; and only mesons, the reggeon, and the pomeron have $n_{q_1} = 0$ and $n_{q_2} \neq 0$. Concerning mesons (not antimesons), if n_{q_1} is odd then it labels a quark and an antiquark if even.

This text and lists of particle numbers can be found on the WWW [6]. The StdHep Monte Carlo standardization project [7] maintains the list of PDG particle numbers, as well as numbering schemes from most event generators and software to convert between the different schemes.

References:

1. G.P. Yost *et al.*, Particle Data Group, Phys. Lett. **B204**, 1 (1988).
2. I. G. Knowles *et al.*, in *"Physics at LEP2"*, CERN 96-01, vol. 2, p. 103.
3. C. Caso *et al.*, Particle Data Group, Eur. Phys. J. **C3**, 1 (1998).
4. T. Sjöstrand *et al.*, in *"Z physics at LEP1"*, CERN 89-08, vol. 3, p. 327.
5. R.M. Barnett *et al.*, Particle Data Group, Phys. Rev. **D54**, 1 (1996).
6. `http://pdg.lbl.gov/mc_particle_id_contents.html`.
7. L. Garren, StdHep, *Monte Carlo Standardization at FNAL*, Fermilab PM0091 and StdHep WWW site:
`http://www-pat.fnal.gov/stdhep.html`.

QUARKS

d	1
u	2
s	3
c	4
b	5
t	6
b'	7
t'	8

LEPTONS

e^-	11
ν_e	12
μ^-	13
ν_μ	14
τ^-	15
ν_τ	16
τ'^-	17
$\nu_{\tau'}$	18

EXCITED PARTICLES

d^*	4000001
u^*	4000002
e^*	4000011
ν_e^*	4000012

GAUGE AND HIGGS BOSONS

g	(9) 21
γ	22
Z^0	23
W^+	24
h^0/H_1^0	25
Z'/Z_2^0	32
Z''/Z_3^0	33
W'/W_2^+	34
H^0/H_2^0	35
A^0/H_3^0	36
H^+	37

DIQUARKS

$(dd)_1$	1103
$(ud)_0$	2101
$(ud)_1$	2103
$(uu)_1$	2203
$(sd)_0$	3101
$(sd)_1$	3103
$(su)_0$	3201
$(su)_1$	3203
$(ss)_1$	3303
$(cd)_0$	4101
$(cd)_1$	4103
$(cu)_0$	4201
$(cu)_1$	4203
$(cs)_0$	4301
$(cs)_1$	4303
$(cc)_1$	4403
$(bd)_0$	5101
$(bd)_1$	5103
$(bu)_0$	5201
$(bu)_1$	5203
$(bs)_0$	5301
$(bs)_1$	5303
$(bc)_0$	5401
$(bc)_1$	5403
$(bb)_1$	5503

TECHNICOLOR PARTICLES

$\pi^0_{\rm tech}$	3000111
$\pi^+_{\rm tech}$	3000211
$\eta^0_{\rm tech}$	3000221
$\rho^0_{\rm tech}$	3000113
$\rho^+_{\rm tech}$	3000213
$\omega^0_{\rm tech}$	3000223

SUSY PARTICLES

$\widetilde{d}_L$	1000001
$\widetilde{u}_L$	1000002
$\widetilde{s}_L$	1000003
$\widetilde{c}_L$	1000004
$\widetilde{b}_1$	1000005[a]
$\widetilde{t}_1$	1000006[a]
$\widetilde{e}_L^-$	1000011
$\widetilde{\nu}_{eL}$	1000012
$\widetilde{\mu}_L^-$	1000013
$\widetilde{\nu}_{\mu L}$	1000014
$\widetilde{\tau}_1^-$	1000015[a]
$\widetilde{\nu}_{\tau L}$	1000016
$\widetilde{d}_R$	2000001
$\widetilde{u}_R$	2000002
$\widetilde{s}_R$	2000003
$\widetilde{c}_R$	2000004
$\widetilde{b}_2$	2000005[a]
$\widetilde{t}_2$	2000006[a]
$\widetilde{e}_R^-$	2000011
$\widetilde{\mu}_R^-$	2000013
$\widetilde{\tau}_2^-$	2000015[a]
$\widetilde{g}$	1000021
$\widetilde{\chi}_1^0$	1000022[b]
$\widetilde{\chi}_2^0$	1000023[b]
$\widetilde{\chi}_1^+$	1000024[b]
$\widetilde{\chi}_3^0$	1000025[b]
$\widetilde{\chi}_4^0$	1000035[b]
$\widetilde{\chi}_2^+$	1000037[b]
$\widetilde{G}$	1000039

SPECIAL PARTICLES

G (graviton)	39
R^0	41
LQ^c	42
reggeon	110
pomeron	990
odderon	9990

for MC internal use 81–100

LIGHT $I = 1$ MESONS

π^0	111
π^+	211
$a_0(980)^0$	9000111
$a_0(980)^+$	9000211
$\pi(1300)^0$	100111
$\pi(1300)^+$	100211
$a_0(1450)^0$	10111
$a_0(1450)^+$	10211
$\pi(1800)^0$	200111
$\pi(1800)^+$	200211
$\rho(770)^0$	113
$\rho(770)^+$	213
$b_1(1235)^0$	10113
$b_1(1235)^+$	10213
$a_1(1260)^0$	20113
$a_1(1260)^+$	20213
$\pi_1(1400)^0$	9000113*
$\pi_1(1400)^+$	9000213*
$\rho(1450)^0$	100113
$\rho(1450)^+$	100213
$\pi_1(1600)^0$	**9010113***
$\pi_1(1600)^+$	**9010213***
$a_1(1640)^0$	**9020113***
$a_1(1640)^+$	**9020213***
$\rho(1700)^0$	30113
$\rho(1700)^+$	30213
$\rho(2150)^0$	**9030113***
$\rho(2150)^+$	**9030213***
$a_2(1320)^0$	115
$a_2(1320)^+$	215
$a_2(1660)^0$	**9000115***
$a_2(1660)^+$	**9000215***
$\pi_2(1670)^0$	10115
$\pi_2(1670)^+$	10215
$a_2(1750)^0$	**9010115***
$a_2(1750)^+$	**9010215***
$\pi_2(2100)^0$	**9020115***
$\pi_2(2100)^+$	**9020215***
$\rho_3(1690)^0$	117
$\rho_3(1690)^+$	217
$\rho_3(2250)^0$	9000117
$\rho_3(2250)^+$	9000217
$a_4(2040)^0$	119
$a_4(2040)^+$	219

LIGHT $I = 0$ MESONS
($u\overline{u}$, $d\overline{d}$, and $s\overline{s}$ Admixtures)

η	221
$\eta'(958)$	331
$f_0(400\text{–}1200)$	9000221
$f_0(980)$	9010221
$\eta(1295)$	100221
$f_0(1370)$	10221
$\eta(1440)$	100331
$f_0(1500)$	9020221
$f_0(1710)$	**10331***
$\eta(1760)$	200221
$f_0(2020)$	**9030221***
$f_0(2060)$	**9040221***
$f_0(2200)$	**9050221***
$\eta(2225)$	**9060221***
$\omega(782)$	223
$\phi(1020)$	333
$h_1(1170)$	10223
$f_1(1285)$	20223
$h_1(1380)$	10333
$f_1(1420)$	20333
$\omega(1420)$	100223
$f_1(1510)$	9000223
$\omega(1650)$	30223*
$\phi(1680)$	100333
$f_2(1270)$	225
$f_2(1430)$	9000225
$f'_2(1525)$	335
$f_2(1565)$	9010225
$f_2(1640)$	9020225
$\eta_2(1645)$	10225
$f_2(1810)$	100225
$\eta_2(1870)$	10335
$f_2(1950)$	9030225
$f_2(2010)$	100335
$f_2(2150)$	9040225
$f_2(2300)$	9050225
$f_2(2340)$	9060225
$\omega_3(1670)$	227
$\phi_3(1850)$	337
$f_4(2050)$	229
$f_J(2220)$	9000339
$f_4(2300)$	9000229

STRANGE MESONS

K^0_L	130
K^0_S	310
K^0	311
K^+	321
$K^*_0(1430)^0$	10311
$K^*_0(1430)^+$	10321
$K(1460)^0$	100311
$K(1460)^+$	100321
$K(1830)^0$	200311
$K(1830)^+$	200321
$K^*_0(1950)^0$	9000311
$K^*_0(1950)^+$	9000321
$K^*(892)^0$	313
$K^*(892)^+$	323
$K_1(1270)^0$	10313
$K_1(1270)^+$	10323
$K_1(1400)^0$	20313
$K_1(1400)^+$	20323
$K^*(1410)^0$	100313
$K^*(1410)^+$	100323
$K_1(1650)^0$	9000313
$K_1(1650)^+$	9000323
$K^*(1680)^0$	30313
$K^*(1680)^+$	30323
$K^*_2(1430)^0$	315
$K^*_2(1430)^+$	325
$K_2(1580)^0$	9000315
$K_2(1580)^+$	9000325
$K_2(1770)^0$	10315
$K_2(1770)^+$	10325
$K_2(1820)^0$	20315
$K_2(1820)^+$	20325
$K^*_2(1980)^0$	100315
$K^*_2(1980)^+$	100325
$K_2(2250)^0$	9010315
$K_2(2250)^+$	9010325
$K^*_3(1780)^0$	317
$K^*_3(1780)^+$	327
$K_3(2320)^0$	9010317
$K_3(2320)^+$	9010327
$K^*_4(2045)^0$	319
$K^*_4(2045)^+$	329
$K_4(2500)^0$	9000319
$K_4(2500)^+$	9000329

CHARMED MESONS

D^+	411
D^0	421
D_0^{*+}	10411
D_0^{*0}	10421
$D^*(2010)^+$	413
$D^*(2007)^0$	423
$D_1(2420)^+$	10413
$D_1(2420)^0$	10423
$D_1(H)^+$	20413
$D_1(H)^0$	20423
$D_2^*(2460)^+$	415
$D_2^*(2460)^0$	425
D_s^+	431
D_{s0}^{*+}	10431
D_s^{*+}	433
$D_{s1}(2536)^+$	10433
$D_{s1}(H)^+$	20433
D_{s2}^{*+}	435

BOTTOM MESONS

B^0	511
B^+	521
B_0^{*0}	10511
B_0^{*+}	10521
B^{*0}	513
B^{*+}	523
$B_1(L)^0$	10513
$B_1(L)^+$	10523
$B_1(H)^0$	20513
$B_1(H)^+$	20523
B_2^{*0}	515
B_2^{*+}	525
B_s^0	531
B_{s0}^{*0}	10531
B_s^{*0}	533
$B_{s1}(L)^0$	10533
$B_{s1}(H)^0$	20533
B_{s2}^{*0}	535
B_c^+	541
B_{c0}^{*+}	10541
B_c^{*+}	543
$B_{c1}(L)^+$	10543
$B_{c1}(H)^+$	20543
B_{c2}^{*+}	545

$c\bar{c}$ MESONS

$\eta_c(1S)$	441
$\chi_{c0}(1P)$	10441
$\eta_c(2S)$	100441
$J/\psi(1S)$	443
$h_c(1P)$	10443
$\chi_{c1}(1P)$	20443
$\psi(2S)$	100443
$\psi(3770)$	30443
$\psi(4040)$	9000443
$\psi(4160)$	9010443
$\psi(4415)$	9020443
$\chi_{c2}(1P)$	445
$\boldsymbol{\psi}$**(3836)**	**9000445***

$b\bar{b}$ MESONS

$\eta_b(1S)$	551
$\chi_{b0}(1P)$	10551
$\eta_b(2S)$	100551
$\chi_{b0}(2P)$	110551
$\eta_b(3S)$	200551
$\chi_{b0}(3P)$	210551
$\Upsilon(1S)$	553
$h_b(1P)$	10553
$\chi_{b1}(1P)$	20553
$\Upsilon_1(1D)$	30553
$\Upsilon(2S)$	100553
$h_b(2P)$	110553
$\chi_{b1}(2P)$	120553
$\Upsilon_1(2D)$	130553
$\Upsilon(3S)$	200553
$h_b(3P)$	210553
$\chi_{b1}(3P)$	220553
$\Upsilon(4S)$	300553
$\Upsilon(10860)$	9000553
$\Upsilon(11020)$	9010553
$\chi_{b2}(1P)$	555
$\eta_{b2}(1D)$	10555
$\Upsilon_2(1D)$	20555
$\chi_{b2}(2P)$	100555
$\eta_{b2}(2D)$	110555
$\Upsilon_2(2D)$	120555
$\chi_{b2}(3P)$	200555
$\Upsilon_3(1D)$	557
$\Upsilon_3(2D)$	100557

LIGHT BARYONS

p	2212
n	2112
Δ^{++}	2224
Δ^{+}	2214
Δ^{0}	2114
Δ^{-}	1114

STRANGE BARYONS

Λ	3122
Σ^{+}	3222
Σ^{0}	3212
Σ^{-}	3112
Σ^{*+}	3224[d]
Σ^{*0}	3214[d]
Σ^{*-}	3114[d]
Ξ^{0}	3322
Ξ^{-}	3312
Ξ^{*0}	3324[d]
Ξ^{*-}	3314[d]
Ω^{-}	3334

CHARMED BARYONS

Λ_c^{+}	4122
Σ_c^{++}	4222
Σ_c^{+}	4212
Σ_c^{0}	4112
Σ_c^{*++}	4224
Σ_c^{*+}	4214
Σ_c^{*0}	4114
Ξ_c^{+}	4232
Ξ_c^{0}	4132
$\Xi_c^{\prime +}$	4322
$\Xi_c^{\prime 0}$	4312
Ξ_c^{*+}	4324
Ξ_c^{*0}	4314
Ω_c^{0}	4332
Ω_c^{*0}	4334
Ξ_{cc}^{+}	4412
Ξ_{cc}^{++}	4422
Ξ_{cc}^{*+}	4414
Ξ_{cc}^{*++}	4424
Ω_{cc}^{+}	4432
Ω_{cc}^{*+}	4434
Ω_{ccc}^{++}	4444

BOTTOM BARYONS

Λ_b^{0}	5122
Σ_b^{-}	5112
Σ_b^{0}	5212
Σ_b^{+}	5222
Σ_b^{*-}	5114
Σ_b^{*0}	5214
Σ_b^{*+}	5224
Ξ_b^{-}	5132
Ξ_b^{0}	5232
$\Xi_b^{\prime -}$	5312
$\Xi_b^{\prime 0}$	5322
Ξ_b^{*-}	5314
Ξ_b^{*0}	5324
Ω_b^{-}	5332
Ω_b^{*-}	5334
Ξ_{bc}^{0}	5142
Ξ_{bc}^{+}	5242
$\Xi_{bc}^{\prime 0}$	5412
$\Xi_{bc}^{\prime +}$	5422
Ξ_{bc}^{*0}	5414
Ξ_{bc}^{*+}	5424
Ω_{bc}^{0}	5342
$\Omega_{bc}^{\prime 0}$	5432
Ω_{bc}^{*0}	5434
Ω_{bcc}^{+}	5442
Ω_{bcc}^{*+}	5444
Ξ_{bb}^{-}	5512
Ξ_{bb}^{0}	5522
Ξ_{bb}^{*-}	5514
Ξ_{bb}^{*0}	5524
Ω_{bb}^{-}	5532
Ω_{bb}^{*-}	5534
Ω_{bbc}^{0}	5542
Ω_{bbc}^{*0}	5544
Ω_{bbb}^{-}	5554

Footnotes to the Tables:

$*$) Numbers or names in bold face are new or have changed since the 1998 *Review* [3].

a) Particulary in the third generation, the left and right sfermion states may mix, as shown. The lighter mixe smaller number.

b) The physical $\widetilde{\chi}$ states are admixtures of the pure $\widetilde{\gamma}$, $\widetilde{Z}^0$, $\widetilde{W}^+$, $\widetilde{H}_1^0$, $\widetilde{H}_2^0$, and $\widetilde{H}^+$ states.

c) In this draft we have only provided one generic leptoquark code. More general classifications according to s flavor content would lead to a host of states, that could be added as the need arises.

d) Σ^* and Ξ^* are alternate names for $\Sigma(1385)$ and $\Xi(1530)$.