

33. MONTE CARLO PARTICLE NUMBERING SCHEME

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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:

$$\pm n_r n_L n_{q1} n_{q2} n_{q3} n_J .$$

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_{q1-3} 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_S^0 and K_L^0). The scheme does not cover particles of spin $J > 4$.
4. Diquarks have 4-digit numbers with $n_{q1} \geq n_{q2}$ and $n_{q3} = 0$.
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 $n_{q1} = 0$ and $n_{q2} \geq n_{q3}$. The special case K_L^0 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 ($\pi^0, \rho^0, \dots$), 22 for the lighter isosinglet ($\eta, \omega, \dots$), and 33 for the heavier isosinglet ($\eta', \phi, \dots$). Since isosinglet mesons are often large mixtures of $u\bar{u} + d\bar{d}$ and $s\bar{s}$ 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_S^0 and K_L^0 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 33.1.

Table 33.1: 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

- 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.
- 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_{q2-3} 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 $n_L = 0, 1, 2, \dots$ 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 $n_{q1} \geq n_{q2} \geq n_{q3}$.
 - b. Two states exist for $J = 1/2$ baryons containing 3 different types of quarks. In the lighter baryon ($\Lambda, \Xi, \Omega, \dots$) the light quarks are in an antisymmetric ($J = 0$) state while for the heavier baryon ($\Sigma^0, \Xi', \Omega', \dots$) they are in a symmetric ($J = 1$) state. In this situation n_{q2} and n_{q3} 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 $SU(2) \times U(1)$ 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 $n = 3$, with technifermions treated like ordinary fermions. States which are ordinary color singlets have $n_r = 0$. Color octets have $n_r = 1$. If a state has non-trivial quantum numbers under the topcolor groups $SU(3)_1 \times SU(3)_2$, the quantum numbers are specified by tech, ij , where i and j are 1 or 2. n_L is then $2i + j$. The coloron, V_8 , is a heavy gluon color octet and thus is 3100021.
 - 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 $n_{q1} \neq 0$; and only mesons, the reggeon, and the pomeron have $n_{q1} = 0$ and $n_{q2} \neq 0$. Concerning mesons (not antimesons), if n_{q1} 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.*, PDG, 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-cpd.fnal.gov/stdhep/>.
8. D.E. Groom *et al.*, PDG, Eur. Phys. J. **C15**, 1 (2000).

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

π_{tech}^0	3000111
π_{tech}^+	3000211
$\pi_{\text{tech}}'^0$	3000221*
η_{tech}^0	3100221*
ρ_{tech}^0	3000113
ρ_{tech}^+	3000213
ω_{tech}^0	3000223
V_8	3100021*
$\pi_{\text{tech},22}^1$	3060111*
$\pi_{\text{tech},22}^8$	3160111*
$\rho_{\text{tech},11}$	3130113*
$\rho_{\text{tech},12}$	3140113*
$\rho_{\text{tech},21}$	3150113*
$\rho_{\text{tech},22}$	3160113*

SUSY

PARTICLES

$\tilde{d}_L$	1000001
$\tilde{u}_L$	1000002
$\tilde{s}_L$	1000003
$\tilde{c}_L$	1000004
$\tilde{b}_1$	1000005 ^a
$\tilde{t}_1$	1000006 ^a
$\tilde{e}_L$	1000011
$\tilde{\nu}_{eL}$	1000012
$\tilde{\mu}_L$	1000013
$\tilde{\nu}_{\mu L}$	1000014
$\tilde{\tau}_1$	1000015 ^a
$\tilde{\nu}_{\tau L}$	1000016
$\tilde{d}_R$	2000001
$\tilde{u}_R$	2000002
$\tilde{s}_R$	2000003
$\tilde{c}_R$	2000004
$\tilde{b}_2$	2000005 ^a
$\tilde{t}_2$	2000006 ^a
$\tilde{e}_R$	2000011
$\tilde{\mu}_R$	2000013
$\tilde{\tau}_2$	2000015 ^a
$\tilde{g}$	1000021
$\tilde{\chi}_1^0$	1000022 ^b
$\tilde{\chi}_2^0$	1000023 ^b
$\tilde{\chi}_1^+$	1000024 ^b
$\tilde{\chi}_3^0$	1000025 ^b
$\tilde{\chi}_4^0$	1000035 ^b
$\tilde{\chi}_2^+$	1000037 ^b
$\tilde{G}$	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
$\rho(1900)^0$	9030113*
$\rho(1900)^+$	9030213*
$\rho(2150)^0$	9040113*
$\rho(2150)^+$	9040213*
$a_2(1320)^0$	115
$a_2(1320)^+$	215
$\pi_2(1670)^0$	10115
$\pi_2(1670)^+$	10215
$a_2(1700)^0$	100115*
$a_2(1700)^+$	100215*
$\pi_2(2100)^0$	9000115*
$\pi_2(2100)^+$	9000215*
$\rho_3(1690)^0$	117
$\rho_3(1690)^+$	217
$\rho_3(1990)^0$	9000117*
$\rho_3(1990)^+$	9000217*
$\rho_3(2250)^0$	9010117*
$\rho_3(2250)^+$	9010217*
$a_4(2040)^0$	119
$a_4(2040)^+$	219

LIGHT $I = 0$ MESONS

$(u\bar{u}, d\bar{d}, \text{ and } s\bar{s} \text{ Admixtures})$	
η	221
$\eta'(958)$	331
$f_0(600)$	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
$f_0(2100)$	9040221*
$f_0(2200)$	9050221
$\eta(2225)$	9060221
$f_0(2330)$	9070221*
$\omega(782)$	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
$h_1(1595)$	9010223*
$\omega(1650)$	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
$f_2(1810)$	9030225*
$\eta_2(1870)$	10335
$f_2(1910)$	9040225*
$f_2(1950)$	100225*
$f_2(2010)$	100335
$f_2(2150)$	9050225*
$f_2(2300)$	9060225*
$f_2(2340)$	9070225*
$\omega_3(1670)$	227
$\phi_3(1850)$	337
$f_4(2050)$	229
$f_J(2220)$	9000339
$f_4(2300)$	9000229

STRANGE MESONS		CHARMED MESONS		$c\bar{c}$ MESONS		LIGHT BARYONS		BOTTOM BARYONS	
K_L^0	130	D^+	411	$\eta_c(1S)$	441	p	2212	Λ_b^0	5122
K_S^0	310	D^0	421	$\chi_{c0}(1P)$	10441	n	2112	Σ_b^-	5112
K^0	311	D_0^{*+}	10411	$\eta_c(2S)$	100441	Δ^{++}	2224	Σ_b^0	5212
K^+	321	D_0^{*0}	10421	$J/\psi(1S)$	443	Δ^+	2214	Σ_b^+	5222
$K_0^*(1430)^0$	10311	$D^*(2010)^+$	413	$h_c(1P)$	10443	Δ^0	2114	Σ_b^{*-}	5114
$K_0^*(1430)^+$	10321	$D^*(2007)^0$	423	$\chi_{c1}(1P)$	20443	Δ^-	1114	Σ_b^{*0}	5214
$K(1460)^0$	100311	$D_1(2420)^+$	10413	$\psi(2S)$	100443	STRANGE BARYONS			
$K(1460)^+$	100321	$D_1(2420)^0$	10423	$\psi(3770)$	30443	Λ	3122	Σ_b^{*+}	5224
$K(1830)^0$	200311	$D_1(H)^+$	20413	$\psi(4040)$	9000443	Σ^+	3222	Ξ_b^-	5132
$K(1830)^+$	200321	$D_1(H)^0$	20423	$\psi(4160)$	9010443	Σ^0	3212	Ξ_b^0	5232
$K_0^*(1950)^0$	9000311	$D_2^*(2460)^+$	415	$\psi(4415)$	9020443	Σ^-	3112	$\Xi_b'^-$	5312
$K_0^*(1950)^+$	9000321	$D_2^*(2460)^0$	425	$\chi_{c2}(1P)$	445	Σ^{*+}	3224 ^d	$\Xi_b'^0$	5322
$K^*(892)^0$	313	D_s^+	431	$\psi(3836)$	9000445	Σ^{*0}	3214 ^d	Ξ_b^{*-}	5314
$K^*(892)^+$	323	D_{s0}^{*+}	10431	$b\bar{b}$ MESONS		Σ^{*-}	3114 ^d	Ξ_b^{*0}	5324
$K_1(1270)^0$	10313	D_s^{*+}	433	$\eta_b(1S)$	551	Ξ^0	3322	Ξ_b^{*-}	5332
$K_1(1270)^+$	10323	$D_{s1}(2536)^+$	10433	$\chi_{b0}(1P)$	10551	Ξ^-	3312	Ω_b^-	5332
$K_1(1400)^0$	20313	$D_{s1}(H)^+$	20433	$\chi_{b0}(2P)$	110551	Ξ^{*0}	3324 ^d	Ω_b^{*-}	5334
$K_1(1400)^+$	20323	D_{s2}^{*+}	435	$\eta_b(2S)$	100551	Ξ^{*-}	3314 ^d	Ξ_{bc}^0	5142
$K^*(1410)^0$	100313	BOTTOM MESONS		$\chi_{b0}(3P)$	210551	Ω^-	3334	Ξ_{bc}^+	5242
$K^*(1410)^+$	100323	B^0	511	$\chi_{b0}(3P)$	210551	CHARMED BARYONS			
$K_1(1650)^0$	9000313	B^+	521	$\Upsilon(1S)$	553	Λ_c^+	4122	Ξ_{bc}^{*0}	5412
$K_1(1650)^+$	9000323	B_0^{*0}	10511	$h_b(1P)$	10553	Σ_c^{++}	4222	Ξ_{bc}^{*+}	5422
$K^*(1680)^0$	30313	B_0^{*+}	10521	$\chi_{b1}(1P)$	20553	Σ_c^+	4212	Ξ_{bc}^{*0}	5414
$K^*(1680)^+$	30323	B^{*0}	513	$\Upsilon_1(1D)$	30553	Σ_c^0	4112	Ξ_{bc}^{*+}	5424
$K_2^*(1430)^0$	315	B^{*+}	523	$\Upsilon(2S)$	100553	Σ_c^{*++}	4224	Ω_{bc}^0	5342
$K_2^*(1430)^+$	325	$B_1(L)^0$	10513	$h_b(2P)$	110553	Σ_c^{*+}	4214	$\Omega_{bc}'^0$	5432
$K_2(1580)^0$	9000315	$B_1(L)^+$	10523	$\chi_{b1}(2P)$	120553	Σ_c^{*0}	4114	Ω_{bc}^{*0}	5434
$K_2(1580)^+$	9000325	$B_1(H)^0$	20513	$\Upsilon_1(2D)$	130553	Ξ_c^+	4232	Ω_{bcc}^+	5442
$K_2(1770)^0$	10315	$B_1(H)^+$	20523	$\Upsilon(3S)$	200553	Ξ_c^0	4132	Ω_{bcc}^{*+}	5444
$K_2(1770)^+$	10325	B_2^{*0}	515	$h_b(3P)$	210553	$\Xi_c'^+$	4322	Ξ_{bb}^-	5512
$K_2(1820)^0$	20315	B_2^{*+}	525	$\chi_{b1}(3P)$	220553	$\Xi_c'^0$	4312	Ξ_{bb}^0	5522
$K_2(1820)^+$	20325	B_s^0	531	$\Upsilon(4S)$	300553	Ξ_c^{*+}	4324	Ξ_{bb}^{*-}	5514
$K_2^*(1980)^0$	100315	B_{s0}^{*0}	10531	$\Upsilon(10860)$	9000553	Ξ_c^{*0}	4314	Ξ_{bb}^{*0}	5524
$K_2^*(1980)^+$	100325	B_s^{*0}	533	$\Upsilon(11020)$	9010553	Ω_c^0	4332	Ω_{bb}^-	5532
$K_2(2250)^0$	9010315	$B_{s1}(L)^0$	10533	$\chi_{b2}(1P)$	555	Ω_c^{*0}	4334	Ω_{bb}^{*-}	5534
$K_2(2250)^+$	9010325	$B_{s1}(H)^0$	20533	$\eta_{b2}(1D)$	10555	Ξ_{cc}^+	4412	Ω_{bbc}^0	5542
$K_3^*(1780)^0$	317	B_{s2}^{*0}	535	$\Upsilon_2(1D)$	20555	Ξ_{cc}^{*+}	4422	Ω_{bbc}^{*0}	5544
$K_3^*(1780)^+$	327	B_c^+	541	$\Upsilon_2(2D)$	100555	Ξ_{cc}^{*+}	4424	Ω_{bbb}^-	5554
$K_3(2320)^0$	9010317	B_{c0}^{*+}	10541	$\chi_{b2}(2P)$	110555	Ω_{cc}^+	4432		
$K_3(2320)^+$	9010327	B_c^{*+}	543	$\eta_{b2}(2D)$	110555	Ω_{cc}^{*+}	4434		
$K_4^*(2045)^0$	319	$B_{c1}(L)^+$	10543	$\Upsilon_2(2D)$	120555	Ω_{ccc}^{*+}	4444		
$K_4^*(2045)^+$	329	$B_{c1}(H)^+$	20543	$\chi_{b2}(3P)$	200555				
$K_4(2500)^0$	9000319	B_{c1}^{*+}	545	$\Upsilon_3(1D)$	557				
$K_4(2500)^+$	9000329	B_{c2}^{*+}	545	$\Upsilon_3(2D)$	100557				

Footnotes to the Tables:

- *) Numbers or names in bold face are new or have changed since the 2000 *Review* [8].
- a) Particularly in the third generation, the left and right sfermion states may mix, as shown. The lighter mixed state is given the smaller number.
- b) The physical $\tilde{\chi}$ states are admixtures of the pure $\tilde{\gamma}$, $\tilde{Z}^0$, $\tilde{W}^+$, $\tilde{H}_1^0$, $\tilde{H}_2^0$, and $\tilde{H}^+$ states.
- c) In this draft we have only provided one generic leptoquark code. More general classifications according to spin, weak isospin and 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 $\Xi(1530)$.