

45. Monte Carlo Particle Numbering Scheme

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The Monte Carlo particle numbering scheme presented here is intended to facilitate interfacing between matrix-element generators, event generators, detector simulators, and analysis packages used in particle physics, and is widely accepted as the “industry standard”. The numbering scheme was introduced in 1988 [1], and has since been revised and expanded in the light of new information on hadronic resonances, and expanded to encompass as yet undiscovered and hypothetical particles.

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. A 9–digit extension is used specifically for tetra- and penta-quark states, and a distinct 10–digit scheme is used for encoding (hyper)nuclear states. 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_S^0 and K_L^0). 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 Tables 15.2, 15.3, and 15.4.
 - (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_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 (π^0, ρ^0, \dots), 22 for the lighter isosinglet (η, ω, \dots), and 33 for the heavier isosinglet (η', ϕ, \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 45.1.
 - (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 45.1: Meson numbering logic. Here qq stands for $n_{q_2} n_{q_3}$.

J	$L = J - 1, S = 1$			$L = J, S = 0$			$L = J, S = 1$			$L = J + 1, S = 1$		
	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 $n_L = 0, 1, 2, \dots$ 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. Codes are assigned to all mesons which are listed in the one-page table at the end of the Meson Summary Table as long as they have a preferred or established spin. Additional heavy meson states expected from heavy quark spectroscopy are also assigned codes.
6. The numbering of baryons is again guided by the nonrelativistic quark model, see Table 15.6. This numbering scheme is illustrated through a few examples in Table 45.2.
- (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 ($\Lambda, \Xi, \Omega, \dots$) 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_{q_2} and n_{q_3} are reversed for the lighter state, so that the smaller number corresponds to the lighter baryon.
- (c) For excited baryons a scheme is adopted, where the n_r label is used to denote the excitation bands in the harmonic oscillator model, see Sec. 15.5. Using the notation employed there, n_r is given by the N -index of the D_N band identifier.
- (d) Further degeneracies of excited hadron multiplets with the same excitation number n_r and spin J are lifted by labelling such multiplets with the n_L index according to their mass, as given by its N or Δ -equivalent.
- (e) In such excited multiplets extra singlets may occur, the $\Lambda(1520)$ being a prominent example. In such cases the ordering is reversed such that the heaviest quark label is pushed to the last position: $n_{q_3} > n_{q_1} > n_{q_2}$.
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

Table 45.2: Some examples of octet (top) and decuplet (bottom) members for the numbering scheme for excited baryons. Here qqq stands for $n_{q_1}n_{q_2}n_{q_3}$. See the text for the definition of the notation. The numbers in parenthesis correspond to the mass of the baryons. The states marked as (?) are not experimentally confirmed.

J^P	(D, L_N^P)	$n_r n_L n_{q_1} n_{q_2} n_{q_3} n_J$	N	Λ_8	Σ	Ξ	Λ_1
Octet							
$1/2^+$	(56, 0_0^+)	00qqq2	(939)	(1116)	(1193)	(1318)	—
$1/2^+$	(56, 0_2^+)	20qqq2	(1440)	(1600)	(1660)	(1690)	—
$1/2^+$	(70, 0_2^+)	21qqq2	(1710)	(1810)	(1880)	(?)	(?)
$1/2^-$	(70, 1_1^-)	10qqq2	(1535)	(1670)	(1620)	(1750)	(1405)
J^P	(D, L_N^P)	$n_r n_L n_{q_1} n_{q_2} n_{q_3} n_J$	Δ	Σ	Ξ	Ω	
Decuplet							
$3/2^+$	(56, 0_0^+)	00qqq4	(1232)	(1385)	(1530)	(1672)	
$3/2^+$	(56, 0_2^+)	20qqq4	(1600)	(1690)	(?)	(?)	
$1/2^-$	(70, 1_1^-)	11qqq2	(1620)	(1750)	(?)	(?)	
$3/2^-$	(70, 1_1^-)	12qqq4	(1700)	(?)	(?)	(?)	

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 and Higgs bosons.
10. Codes 81–100 are reserved for generator-specific pseudoparticles and concepts. Codes 901–930, 1901–1930, 2901–2930, and 3901–3930 are for additional components of Standard Model parton distribution functions, where the latter three ranges are intended to distinguish left/right/ longitudinal components. Codes 998 and 999 are reserved for GEANT tracking purposes.
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. The subrange 61–80 can be used for new heavier fermions in generic models, where partners to the SM fermions would have codes offset by 60. If required, however, other assignments could be made.
 - (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 $n = 4$ and $n_r = 0$.
 - (g) Within several scenarios of new physics, it is possible to have colored particles sufficiently long-lived for color-singlet hadronic states to form around them. In the context of supersymmetric scenarios, these states are called R -hadrons, since they carry odd R -parity. R -hadron codes, defined here, should be viewed as templates for corresponding codes also in other scenarios, for any long-lived particle that is either an unflavored color octet or a flavored color triplet. The R -hadron code is obtained by combining the SUSY particle code with a code for the light degrees of freedom, with as many intermediate zeros removed from the former as required to make place for the latter at the end. (To exemplify, a sparticle $n00000n_{\tilde{q}}$ combined with quarks q_1 and q_2 obtains code $n00n_{\tilde{q}}n_{q_1}n_{q_2}n_J$.) Specifically, the new-particle spin decouples in the limit of large masses, so that the final n_J digit is defined by the spin state of the light-quark system alone. An appropriate number of n_q digits is used to define the ordinary-quark content. As usual, 9 rather than 21 is used to denote a gluon/gluino in composite states. The sign of the hadron agrees with that of the constituent new particle (a color triplet) where there is a distinct new antiparticle, and else is defined as for normal hadrons. Particle names are R with the flavor content as lower index.
 - (h) A black hole in models with extra dimensions has code 5000040. Kaluza-Klein excitations in models with extra dimensions have $n = 5$ or $n = 6$, to distinguish excitations of left- or right-handed fermions or, in case of mixing, the lighter or heavier state (cf. 11d). The nonzero n_r digit gives the radial excitation number, in scenarios where the level spacing allow these to be distinguished. Should the model also contain supersymmetry, excited SUSY states would be denoted by an $n_r > 0$, with $n = 1$ or 2 as usual. Should some colored states be long-lived enough that hadrons would form around them, the coding strategy of 11g applies, with the initial two nn_r digits preserved in the combined code.
 - (i) Magnetic monopoles and dyons are assumed to have one unit of Dirac monopole charge and a variable integer number $n_{q_1}n_{q_2}n_{q_3}$ units of electric charge. Codes $411n_{q_1}n_{q_2}n_{q_3}0$ are then used when the magnetic and electrical charge sign agree and $412n_{q_1}n_{q_2}n_{q_3}0$ when they disagree, with the overall sign of the particle set by the magnetic charge. For now no spin information is provided.
 - (j) The nature of Dark Matter (DM) is not known, and therefore a definitive classification is too early. Candidates within specific scenarios are classified therein, such as 1000022 for the lightest neutralino. Generic fundamental states can be given temporary codes in the range 51 - 60, with 51, 52 and 53 reserved for spin 0, 1/2 and 1 ones (this could also be an axion state). Generic mediators of s-channel DM pair creation or annihilation can be given codes 54 and 55 for spin 0 or 1 ones. Separate antiparticles, with negative codes, may or may not exist. More elaborate new scenarios should be constructed with $n = 5$ and $n_r = 9$.
 - (k) Hidden Valley particles have $n = 4$ and $n_r = 9$, and trailing numbers in agreement with their nearest-analog standard particles, as far as possible. Thus 4900021 is the gauge boson g_v of a confining gauge field, $490000n_{q_v}$ and $490001n_{\ell_v}$ fundamental constituents charged or not under this, 4900022 is the γ_v of a non-confining field, and $4900n_{q_{v1}}n_{q_{v2}}n_J$ a Hidden Valley meson.
12. Occasionally program authors add their own states. To avoid confusion, these should be flagged by setting $nn_r = 99$.

LIGHT BARYONS		Ξ^0	3322	$\Xi_c^{0\prime}$	4312	Σ_b^+	5222	$\Omega_{bc}^{0\prime}$	5432
p	2212	Ξ^-	3312	Ξ_c^{*+}	4324	Σ_b^{*-}	5114	Ω_{bc}^{*0}	5434
n	2112	Ξ^{*0}	3324 ^c	Ξ_c^{*0}	4314	Σ_b^{*0}	5214	Ω_{bcc}^+	5442
Δ^{++}	2224	Ξ^{*-}	3314 ^c	Ω_c^0	4332	Σ_b^{*+}	5224	Ω_{bcc}^{*+}	5444
Δ^+	2214	Ω^-	3334	Ξ_c^{*0}	4334	Ξ_b^-	5132	Ξ_{bb}^-	5512
Δ^0	2114	CHARMED BARYONS		Ξ_{cc}^+	4412	Ξ_b^0	5232	Ξ_{bb}^0	5522
Δ^-	1114	Λ_c^+	4122	Ξ_{cc}^{++}	4422	Ξ_b^{*-}	5312	Ξ_{bb}^{*-}	5514
STRANGE BARYONS		Σ_c^{++}	4222	Ξ_{cc}^{*+}	4414	$\Xi_b^{0\prime}$	5322	Ξ_{bb}^{*0}	5524
Λ	3122	Σ_c^+	4212	Ξ_{cc}^{*+}	4424	Ξ_b^{*-}	5314	Ω_{bb}^-	5532
Σ^+	3222	Σ_c^0	4112	Ω_{cc}^+	4432	Ξ_b^{*0}	5324	Ω_{bb}^{*0}	5534
Σ^0	3212	Σ_c^{*+}	4224	Ω_{cc}^{*+}	4434	Ω_b^-	5332	Ω_{bbc}^0	5542
Σ^-	3112	Σ_c^{*0}	4214	Ω_{ccc}^{*+}	4444	Ω_b^{*-}	5334	Ω_{bbc}^{*0}	5544
Σ^{*+}	3224 ^c	Σ_c^0	4112	BOTTOM BARYONS		Ξ_{bc}^0	5142	Ω_{bbb}^-	5554
Σ^{*0}	3214 ^c	Σ_c^{*+}	4224	Λ_b^0	5122	Ξ_{bc}^+	5242	PENTA-QUARKS	
Σ^{*-}	3114 ^c	Σ_c^{*0}	4214	Σ_b^-	5112	$\Xi_{bc}^{0\prime}$	5412	Θ^+	100221132*
		Ξ_c^+	4232	Σ_b^0	5212	$\Xi_{bc}^{+\prime}$	5422	Φ^{--}	100331122*
		Ξ_c^0	4132			Ξ_{bc}^{*0}	5414		
		$\Xi_c^{+\prime}$	4322			Ξ_{bc}^{*+}	5424		
						Ω_{bc}^0	5342		

Footnotes to the tables:

- *) Numbers or names in bold face are new or have changed since the 2020 *Review*.
- a) Particular 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) Σ^* and Ξ^* are alternate names for $\Sigma(1385)$ and $\Xi(1530)$.

References

- [1] G. P. Yost *et al.* (Particle Data Group), *Phys. Lett.* **B204**, 1 (1988).
- [2] G. Audi *et al.*, *Nucl. Phys.* **A729**, 3 (2003).