44. 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, PYTHIA, and SHERPA, and interfaces, e.g. /HEPENV/ and HepMC.

The general form is a 7-digit number:

\[ \pm n_1 n_2 q_1 q_2 r_1 r_2 r_3 \]

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) \( n_1 \ldots n_4 \) are quark numbers used to specify the quark content, while the rightmost digit \( n_5 = 2J + 1 \) gives the system's spin (except for the \( K^0 \) and \( K^0 \)). The scheme does not cover particles of spin \( J > 4 \).

4. Diquarks have 4-digit numbers with \( n_4 > n_2 \) and \( n_2 = 0 \).

5. The numbering of mesons is guided by the nonrelativistic (L-S decoupled) quark model, as listed in Tables 15.2 and 15.3.

   a. The numbers specifying the meson's quark content conform to the convention \( n_1 = 0 \) and \( n_2 \geq n_3 \). The special case \( K^0 \) 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 isorotilet \((u^0, d^0, s^0)\), 22 for the lighter isosinglet \((u,d,s)\), and 33 for the heavier isosinglet \((u^0, d^0, s^0)\). 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 \( K^0 \) and \( K^0 \) respectively.

   d. The fifth digit \( n_5 \) 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: \((L,S) = (J - 1,1) \quad n_5 = 0 \), \((J,0) \quad n_5 = 1 \), \((J,1) \quad n_5 = 2 \) and \((J + 1,1) \quad n_5 = 3 \). For the exceptional case \( J = 0 \) the numbers are \((0,0) \quad n_5 = 0 \) and \((1,1) \quad n_5 = 1 \) (i.e. \( n_5 = L \)). See Table 44.1.

**Table 44.1:** Meson numbering logic. Here qq stands for \( n_2 q_2 r_2 q_1 r_1 \).

<table>
<thead>
<tr>
<th>( J )</th>
<th>code</th>
<th>( c_D / c_S )</th>
<th>L</th>
<th>code</th>
<th>( c_D / c_S )</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00</td>
<td>000q1</td>
<td>0++</td>
<td>0</td>
<td>00</td>
<td>000q1</td>
</tr>
<tr>
<td>1</td>
<td>000q3</td>
<td>1−</td>
<td>1</td>
<td>00</td>
<td>00</td>
<td>000q1</td>
</tr>
<tr>
<td>2</td>
<td>000q5</td>
<td>2+</td>
<td>1</td>
<td>00</td>
<td>00</td>
<td>000q1</td>
</tr>
<tr>
<td>3</td>
<td>000q7</td>
<td>3−</td>
<td>2</td>
<td>00</td>
<td>00</td>
<td>000q1</td>
</tr>
</tbody>
</table>

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 44.2.

   a. The numbers specifying a baryon's quark content are such that in general \( n_2 > n_4 \geq n_3 \).

   b. Two states exist for \( J = 1/2 \) baryons containing 3 different types of quarks. In the lighter baryon (\( L, \Xi, \Omega \ldots \)) the light quarks are in an antisymmetric \((J = 0)\) state while for the heavier baryon (\( \Sigma^0, \Xi^0, \Omega^0 \ldots \)) they are in a symmetric \((J = 1)\) state. In this situation \( n_2 \) and \( n_3 \) 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. 15.4. Using the notation employed there, \( n_r \) is given by the \( X \)-index of the \( P_\lambda \) 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 \( \Delta \)-equivalent.

   e. In such excited multiplets extra singlet states may occur, the \( (1520) \) (\( \Lambda \)) being a prominent example. In such cases the ordering is reversed such that the heaviest quark label is pushed to the last position: \( n_q \geq n_r \).

   f. For pentaquark states \( n = 9, n_r n_L n_q q_1 r_1 \) gives the four quark numbers in order \( n_r \geq n_q \geq n_2 \geq n_3 \). \( n_q \) gives the antiquark number, and \( n_J = 2J + 1 \), with the assumption that \( J = 1/2 \) for the states currently reported.

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 pomerlon 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 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. 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. See Table 44.3.

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
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- Technicolor states have \( n = 3 \), with technifermions treated like ordinary fermions. States which are ordinary color singlets have \( n_0 = 0 \). Color octets have \( n_0 = 1 \). If a state has non-trivial quantum numbers under the topcolor group SU(3)_T \times SU(3)_2, the quantum numbers are specified by tech,\(ij\), where \( i \) and \( j \) are 1 or 2. \( n_{ij} \) is then \( 2i + j \). The coloron, \( V_8 \), is a heavy gluon color octet and thus is 3100021.

- Excited (composite) quarks and leptons are identified by setting \( n = 4 \) and \( n_0 = 0 \).

- 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 \( \tilde{\nu}_e \tilde{\nu}_\tau \) combined with quarks \( q_1 \) and \( q_2 \) obtains code \( s000q qq \) instead of \( s000q\tilde{\nu}_\tau\tilde{\nu}_\tau n_\downarrow \).

- Specifically, the new-particle spin \( \text{isomer level, with} \) \( I = 0 \). Concerning mesons (not antimesons), if \( n = 0 \) or \( n_0 \neq 0 \), then \( \Lambda \) is \( 0 \). Concerning mesons (not antimesons), if \( n_0 \neq 0 \) then \( \Lambda \) is \( 0 \). Concerning mesons (not antimesons), if \( n_0 \neq 0 \) and \( n_0 \neq 0 \), then \( \Lambda \) is \( 0 \).

- Concerning the non-99 numbers, it may be noted that only quarks, excited quarks, squarks, and diquarks have \( n_q = 0 \); only diquarks, baryons (including pentaquarks), and the odderon have \( n_q > 0 \); and only mesons, the reggun, and the pomerion have \( n_q = 0 \) and \( n_0 = 0 \). Concerning mesons (not antimesons), if \( n_0 \neq 0 \) then it labels a quark and an antiquark if even.

<table>
<thead>
<tr>
<th>( J^P )</th>
<th>( (D, L, n) )</th>
<th>( n_{1n} n_0 n_1 n_q n_0 n_1 n_q n_0 n_q )</th>
<th>( \Delta )</th>
<th>( \Sigma )</th>
<th>( \Xi )</th>
<th>( \Lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1/2^+ )</td>
<td>( (56, 0, 2) )</td>
<td>00qqq4</td>
<td>(1232)</td>
<td>(1385)</td>
<td>(1530)</td>
<td>(1672)</td>
</tr>
<tr>
<td>( 1/2^- )</td>
<td>( (56, 0, 2) )</td>
<td>00qqq4</td>
<td>(1232)</td>
<td>(1385)</td>
<td>(1530)</td>
<td>(1672)</td>
</tr>
<tr>
<td>( 1/2^- )</td>
<td>( (70, q, 2) )</td>
<td>11qqq2</td>
<td>(1620)</td>
<td>(1750)</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td>( 3/2^- )</td>
<td>( (70, q, 2) )</td>
<td>12qqq4</td>
<td>(1700)</td>
<td>(?)</td>
<td>(?)</td>
<td>(?)</td>
</tr>
</tbody>
</table>

This text and full lists of particle numbers can be found online [5].

References:
2. L.G. Knowles et al., CERN 96-01, v. 2, p. 103.
QUARKS  
\(d\)  
\(u\)  
\(s\)  
\(c\)  
\(b\)  
\(t\)  
\(b'\)  
\(t'\)  

DIQUARKS  
\( (dd)_{1} \)  
\( (ud)_{3} \)  
\( (sd)_{1} \)  
\( (cu)_{1} \)  
\( (ub)_{1} \)  
\( (ub)_{2} \)  
\( (ub)_{3} \)  
\( (sb)_{0} \)  
\( (sb)_{1} \)  
\( (sb)_{2} \)  
\( (sb)_{3} \)  
\( (sb)_{4} \)  
\( (sb)_{5} \)  
\( (sb)_{6} \)  

LEPTONS  
\(e^-\)  
\(\nu_e\)  
\(\mu^-\)  
\(\tau^-\)  
\(e^+\)  
\(\nu_e\)  
\(\mu^+\)  
\(\tau^+\)  

GAUGE AND HIGGS BOSONS  
\(g\)  
\(\gamma\)  
\(Z^0\)  
\(W^+\)  
\(h^0/H^0_1\)  
\(Z'/Z^0_2\)  
\(Z''/Z^0_3\)  
\(W'/W_2^+\)  
\(H^0/H_2^0\)  
\(A^0/H_3^0\)  
\(H^+\)  

SUSY PARTICLES  
\(\tilde{d}_L\)  
\(\tilde{u}_L\)  
\(\tilde{s}_L\)  
\(\tilde{c}_L\)  
\(\tilde{b}_1\)  
\(\tilde{t}_1\)  
\(\tilde{t}\)  
\(\tilde{R}\)  
\(\tilde{\mu}_R\)  
\(\tilde{\tau}_\nu\)  
\(\tilde{\tau}_\nu\)  
\(\tilde{\tau}_{R}\)  
\(\tilde{z}\)  
\(\tilde{G}\)  
\(\tilde{b}_2\)  
\(\tilde{b}_{2}^c\)  
\(\tilde{b}_{2}^d\)  
\(\tilde{b}_{2}^e\)  
\(\tilde{b}_{2}^f\)  
\(\tilde{b}_{2}^g\)  
\(\tilde{b}_{2}^h\)  
\(\tilde{b}_{2}^i\)  
\(\tilde{b}_{2}^j\)  
\(\tilde{b}_{2}^k\)  
\(\tilde{b}_{2}^l\)  
\(\tilde{b}_{2}^m\)  
\(\tilde{b}_{2}^n\)  
\(\tilde{b}_{2}^o\)  
\(\tilde{b}_{2}^p\)  
\(\tilde{b}_{2}^q\)  
\(\tilde{b}_{2}^r\)  
\(\tilde{b}_{2}^s\)  
\(\tilde{b}_{2}^t\)  
\(\tilde{b}_{2}^u\)  
\(\tilde{b}_{2}^v\)  
\(\tilde{b}_{2}^w\)  
\(\tilde{b}_{2}^x\)  
\(\tilde{b}_{2}^y\)  
\(\tilde{b}_{2}^z\)  

\[ \text{LIGHT } I = 1 \text{ MESONS} \]  
\[ \pi^0 \]  
\[ \pi^+ \]  
\[ \rho(980)^0 \]  
\[ \rho(980)^+ \]  
\[ \pi(1300)^0 \]  
\[ \pi(1300)^+ \]  
\[ \rho(1450)^0 \]  
\[ \rho(1450)^+ \]  
\[ \pi(1800)^0 \]  
\[ \pi(1800)^+ \]  
\[ \rho(770)^0 \]  
\[ \rho(770)^+ \]  
\[ \rho(1235)^0 \]  
\[ \rho(1235)^+ \]  
\[ \pi(1260)^0 \]  
\[ \pi(1260)^+ \]  

\[ \text{LIGHT } I = 0 \text{ MESONS} \]  
\[ \eta \]  
\[ \eta' \]  
\[ \phi(1020) \]  
\[ \phi(1170) \]  
\[ \phi(1250) \]  
\[ \phi(1380) \]  
\[ \phi(1420) \]  
\[ \omega(1420) \]  
\[ \omega(1510) \]  
\[ \omega(1595) \]  
\[ \omega(1650) \]  
\[ \phi(1680) \]  
\[ \phi(1720) \]  

\[ \text{SPECIAL PARTICLES} \]  
\( G \)  
\( R^0 \)  
\( LQ^c \)  
\( DM(S = 0) \)  
\( DM(S = 1/2) \)  
\( DM(S = 1) \)  
\( \text{reggeon} \)  
\( \text{pomeron} \)  
\( \text{odderon} \)  

for MC internal use \( 81-100, 901-930^* \), \( 1901-1930^*, 2901-2930^* \) and \( 3901-3930^* \)
Footnotes to the Tables:

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 $\chi$ states are admixtures of the pure $\tilde{\Xi}$, $\tilde{Z}$, $\tilde{W}$, $\tilde{H}$, $\tilde{H}^0$, and $\tilde{H}^+$ states.

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