The UrQMD (Frankfurt Nantes Duke) user guide

The **UrQMD** group

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Warning: This document is updated regularly. In its current form it describes the handling of **UrQMD Version 3.4**. If you are using a different version of **UrQMD**, please obtain the manual from `http://urqmd.org/documentation`
The authors give no warranty to the correct functioning of the **UrQMD** program. Use this program at your own risk. Please send all bug–reports to the following e-mail address:

`urqmd@urqmd.org`

and a copy to

`bleicher@th.physik.uni-frankfurt.de`

Contents

1 General Information and references

The Ultra Relativistic Quantum Molecular Dynamics (**UrQMD**) model is a transport model for simulating heavy ion collisions in the energy range from SIS to RHIC (use at LHC is at your own risk). It runs on various UNIX-based computing platforms. Current implementations include IBM/AIX (xlf), GNU/Linux (gfortran, ifc), SGI/IRIX, DEC-UNIX and Sun/Solaris, see Section 4.

UrQMD is designed as multipurpose tool for studying a wide variety of heavy ion related effects ranging from multifragmentation and collective flow to particle production and correlations. For hard pQCD scatterings, the model includes the PYTHIA routines from the LUND group [1].

This document is no introduction to the physics of **UrQMD**. Its purpose is to serve as a manual to the experienced physicist on how to run the program. A detailed model description can be found in the following two articles.

[2] *Microscopic Models for Ultrarelativistic Heavy Ion Collisions*
S. A. Bass, M. Belkacem, M. Bleicher, M. Brandstetter, L. Bravina, C. Ernst, L. Gerland, M. Hofmann, S. Hofmann, J. Konopka, G. Mao, L. Neise, S. Soff, C. Spieles, H. Weber, L. A. Winckelmann, H. Stöcker, W. Greiner, C. Hartnack, J. Aichelin and N. Amelin.
Prog. Part. Nucl. Phys. **41** (1998) 225–370.

[3] *Relativistic Hadron-Hadron Collisions and the Ultra-Relativistic Quantum Molecular Dynamics Model (UrQMD)*
M. Bleicher, E. Zabrodin, C. Spieles, S.A. Bass, C. Ernst, S. Soff, H. Weber, H. Stöcker and W. Greiner.
J. Phys. **G25** (1999) 1859–1896.

For the hybrid model including an ideal fluid-dynamic evolution for the hot and dense stage please refer to

[4] *Fully integrated transport approach to heavy ion reactions with an intermediate hydrodynamic stage*
H. Petersen, J. Steinheimer, G. Burau, M. Bleicher and H. Stöcker.
Phys. Rev. C **78** (2008) 044901.

The hybrid calculations have been tested to give reasonable results in the energy range from $E_{\rm lab} = 2-160$ AGeV in standard parameter calculations. For calculations at larger energies, please make use of `CTParameter(61)`, `CTParameter(63)`, `CTParameter(65)` and `CTParameter(66)` and possibly also `CTParameter(69)` and `CTParameter(70)` (see Table 4) to create a stable simulation.

The fluid-dynamic evolution is carried out by the Smooth and Sharp Transport Algorithm (SHASTA) in its implementation for relativistic heavy ion collisions as it is decribed in

[5] *Relativistic hydrodynamics for heavy ion collisions. 1. General aspects and expansion into vacuum*
D. H. Rischke, S. Bernard and J. A. Maruhn.
Nucl. Phys. A **595** (1995) 346.

[6] *Relativistic hydrodynamics for heavy ion collisions. 2. Compression of nuclear matter and the phase transition to the quark - gluon plasma*
D. H. Rischke, Y. Pursun and J. A. Maruhn.
Nucl. Phys. A **595** (1995) 383.

For the different equations of state during the fluid-dynamic evolution the reader is refered to the following references:

[7] Hadron Resonance Gas: CT0 47 2
Particle ratios at RHIC: Effective hadron masses and chemical freeze-out
D. Zschiesche, S. Schramm, J. Schaffner-Bielich, H. Stöcker and W. Greiner.
Phys. Lett. B **547** (2002) 7.

[6] Bag Model: CTO 47 3
Hadronic SU(2)$_f$ model and ideal gas of massles quarks and gluons are matched via a Maxwell construction:
Relativistic hydrodynamics for heavy ion collisions. 2. Compression of nuclear matter and the phase transition to the quark - gluon plasma
D. H. Rischke, Y. Pursun and J. A. Maruhn.
Nucl. Phys. A **595** (1995) 383.

[8] Chiral + Deconfinement EoS: CT0 47 5 (Standard EoS)
Smooth crossover between a chiral hadronic model and an interacting constituent quark model:
The hadronic SU(3) Parity Doublet Model for Dense Matter, its extension to quarks and the strange equation of state
J. Steinheimer, S. Schramm and H. Stöcker.
Phys. Rev. C **84**, 045208 (2011)

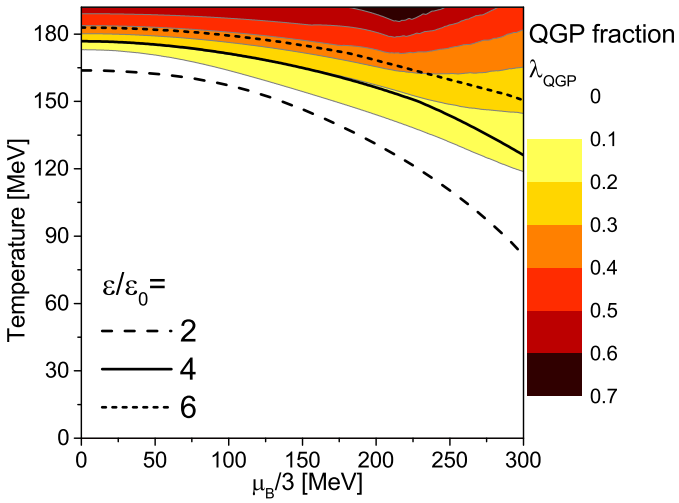

Figure 1: Quark Gluon Plasma fraction λ_{QGP} in the T-μ_B plane of the Chiral + Deconfinement EoS. Also indicated are lines of constant energy density ϵ/ϵ_0.

1.1 How to read this manual

In order to improve readability of this manual, special words such as the names of files, variables, formatting information etc. are specially highlighted:

files File names are preceeded by a little file-symbol and typeset in typewriter font. The file "urqmd.f" is typeset "`urqmd.f`".

filehandles FORTRAN output file handles (used to distinguish the different output formats in **UrQMD**) are depicted with a little sketch of two colliding nuclei and the file handle number in blue letters. The output file handle 14 is typeset "14".

executables The name of programs and other commands is underlined: The program "init" is typeset as "init".

formats Format specifiers are typeset in typewriter font and enclosed in parentheses "()". The content is set in dark-blue letters: Format "A3" is typeset `(A3)`. All format specifications in this manual are in FORTRAN 77 convention. Since FORTRAN 77 behaves differently from standard **&**printf( )-routines present in most modern programming languages in the case of over- or underflow, we rather not give the corresponding **&**printf( )-codes. Here is a quick overview (the directives are case-insensitive):

- **`(a5)`** "%5s": 5 character wide string, e.g. "`UrQMD`".
- **`(i6)`** "% 6d": 6 digits wide integer. Padded with spaces, e.g. "␣␣`1234`"
- **`(f4.1)`** "%4.1f": 4 characters wide floating point value with 1 decimal place, e.g. "␣`3.4`"
- **`(e12.4)`** "%12.4e": 12 characters wide number in scientific notation with four decimal places, e.g. "␣␣`3.4000e+00`"
- **`(2x)`** Two spaces.
- **`(,)`** Simple concatenation of two of the above, as in `(a5,i4)` = "%5s%4d".

functions Functions are preceeded by a bold ampersand ("&") and succeeded by an empty pair of parentheses ("()") and typeset in dark-red letters. The function "printf" is typeset "**&**printf( )".

input file flags Input file flags (the three-letter codes at the beginning of each line in the input file) are typeset in *italic* orange letters: Flag "nev" is typeset "*nev*"

input file options Input file options (the options to input file flags) are typeset in `type-writer` cyan letters: Flag "ebeam" is typeset "`ebeam`". (See Section 5)

1.1.1 Wording

There is some confusion on the appropriate terms for last collisions and interfaces between cascade- and fluid-dynamic calculations. For this manual, the following wording is used (hopefully consistently):

fluidization The interface from a particle-based description (cascade or transport mode) to a fluid-dynamical (= hydrodynamical) description. In **UrQMD**, the fluid is in perfect thermal equilibrium, thus, this transition includes instant thermal equilibration. This is a numerical occurrence, i.e. the numerical description of the matter changes, but not (necessarily) the physical description.

phase transition A transition **within the fluid**, which may or may not occur, depending on the Equation of State used in the fluid dynamical propagation. This is **only** a physical transition, the description of the matter is the same on both sides of the phase transition – i.e., that of a fluid.

particlization The interface from a fluid-based description to a particle-based description. This is numerics, only: the physical content of the matter is the same on both sides of the interface (and guaranteed to be a hadron resonance gas), but the description changes. Particlization is the part of the model where the Cooper-Frye formula is applied.

freeze-out The last interaction. This typically happens in the hadronic phase, regardless of possible fluid-dynamic calculations beforehand. Each final particle has a freeze-out event.

We thank Pasi Huovinen for the initializing discussion about these words and for introducing the word "particlization" to us.

1.2 Known Particle species

Particle species in **UrQMD** are distinguished by two integer numbers ityp and iso3. iso3 is **twice** the third component of the isospin vector. Negative itypes are the anti-particles to the corresponding particles with positive itypes (anti-baryons and anti-strange/anti-charmed mesons). itypes smaller than 100 correspond to baryons, itypes between 100 and 999 correspond to mesons. Particle species unknown to **UrQMD** (as may be created in PYTHIA) have their HEP-Particle ID [9] ± 1000 (the sign is chosen so that $|\text{ityp}| > 1000$), to avoid conflicts. See the PYTHIA manual for the HEP scheme of naming particle species.

Table 1 contains the itypes of all baryon species used in **UrQMD**, and Table 2 contains the itypes of all meson species used in **UrQMD**.

Please Note: charmed particle support in **UrQMD** is very rudimentary and should be considered experimental at this stage.

2 User support

UrQMD users are encouraged to join the user@urqmd.org e-mail list and post questions concerning **UrQMD** to this list. When registering as **UrQMD** user at http://urqmd.org/, subscription to the list will happen automatically. For further questions and bug reports, the **UrQMD**-developers can be contacted via urqmd@urqmd.org

ityp	nucleon	ityp	delta	ityp	lambda	ityp	sigma	ityp	xi	ityp	omega
1	N_{938}	17	Δ_{1232}	27	Λ_{1116}	40	Σ_{1192}	49	Ξ_{1317}	55	Ω_{1672}
2	N_{1440}	18	Δ_{1600}	28	Λ_{1405}	41	Σ_{1385}	50	Ξ_{1530}		
3	N_{1520}	19	Δ_{1620}	29	Λ_{1520}	42	Σ_{1660}	51	Ξ_{1690}		
4	N_{1535}	20	Δ_{1700}	30	Λ_{1600}	43	Σ_{1670}	52	Ξ_{1820}		
5	N_{1650}	21	Δ_{1900}	31	Λ_{1670}	44	Σ_{1775}	53	Ξ_{1950}		
6	N_{1675}	22	Δ_{1905}	32	Λ_{1690}	45	Σ_{1790}	54	Ξ_{2025}		
7	N_{1680}	23	Δ_{1910}	33	Λ_{1800}	46	Σ_{1915}				
8	N_{1700}	24	Δ_{1920}	34	Λ_{1810}	47	Σ_{1940}				
9	N_{1710}	25	Δ_{1930}	35	Λ_{1820}	48	Σ_{2030}				
10	N_{1720}	26	Δ_{1950}	36	Λ_{1830}						
11	N_{1900}			37	Λ_{1890}						
12	N_{1990}			38	Λ_{2100}						
13	N_{2080}			39	Λ_{2110}						
14	N_{2190}										
15	N_{2200}										
16	N_{2250}										

Table 1: Baryon-itypes used in **UrQMD**. Antibaryons carry a negative sign.

ityp	0^{-+}	ityp	1^{--}	ityp	0^{++}	ityp	1^{++}	ityp	charmed
101	π	104	ρ	111	a_0	114	a_1	133	D
106	K	108	K^*	110	K_0^*	113	K_1^*	134	D^*
102	η	103	ω	105	f_0	115	f_1	135	J/Ψ
107	η'	109	ϕ	112	f_0^*	116	f_1'	136	χ_c
ityp	1^{+-}	**ityp**	2^{++}	**ityp**	$(1^{--})^*$	**ityp**	$(1^{--})^{**}$	137	Ψ'
122	b_1	118	a_2	126	ρ_{1450}	130	ρ_{1700}	138	D_s
121	K_1	117	K_2^*	125	K_{1410}^*	129	K_{1680}^*	139	D_s^*
123	h_1	119	f_2	127	ω_{1420}	131	ω_{1662}		
124	h_1'	120	f_2'	128	ϕ_{1680}	132	ϕ_{1900}		

Table 2: Meson-itypes in **UrQMD**, sorted with respect to spin and parity, included into the **UrQMD** model. Mesons with strangeness -1 (or charm -1 for itypes > 132) carry a negative sign. See Table 9 for a list ordered by Meson itypes.

3 Copyright

UrQMD source and documentation are provided freely for the purpose of checking and reproducing published results of the authors.

The Open Standard Codes and Routines (OSCAR)-Group has established – for good reasons – guidelines for reproducibility, usage and quality control of simulations codes for pA and AA collisions.

UrQMD is a complex model. In order to ensure that it is used correctly, that all results are reproducible and that the proper credits are given we ask for your agreement to the following copyright and safeguard mechanisms in the OSCAR spirit.

The **UrQMD** collaboration favors cooperation and joint projects with outside researchers. We encourage experimental collaborations to compare their results to **UrQMD**. We support you and/or cooperate on any sensible project related to **UrQMD**.

If you are interested in a project, please contact us.

Projects without the participation of the **UrQMD**-Collaboration are accepted, if the project is not a current thesis topic of any **UrQMD**-Collaboration member.

We expect that the code authors are informed about any changes and modifications made to the code. Any changes to the official version must be documented.

The only official source for the UrQMD program is the web page `http://urqmd.org`.

The code or any fragments thereof shall not be given away to third parties. Similarily, events generated with **UrQMD** shall not be given to third parties without consent of the code authors at Frankfurt.

4 Compiling and running the program

To compile **UrQMD** one needs a FORTRAN77 compiler and GNU-make. The GNU-make program is available on `ftp.gnu.org` (**Please Note:** on many old UNIX systems GNU-make is called gmake). Compilation is initiated by issuing the make command at the command-prompt in the **UrQMD** subdirectory. After successful compilation the binary has the name `urqmd.ARCH`, where ARCH is the machine type as given by uname -m. For further possibilities of using make with **UrQMD**, type (g)make help.

In order to run **UrQMD** one needs to define the running parameters with an input file. The input file is made accessible to **UrQMD** by attaching its name to the environment-variable ftn09. The output files are attached in the same fashion via the environment variables ftn13 through ftn20. Old events are read from the file specified in environment variable ftn10. Listing 1 shows how **UrQMD** is started on a generic UNIX system (here Linux using the Bash Shell). A sample file (`runqmd.bash`) is provided as part of the **UrQMD** program.

Please Note: during compilation, **UrQMD** is run once to create a file `tables.dat` which contains numerical interpolations. If that file doesn't exist, **UrQMD** creates it first (otherwise it just reads the tables from that file). Make sure **UrQMD** has been started once to create the tables before you start multiple instances of **UrQMD** at the same time (as may happen when you submit multiple jobs on a cluster).

Listing 1: running the **UrQMD** program (POSIX-compatible shell)

```
export ftn09=inputfile
export ftn13=outputfile_with_freezeout
export ftn14=outputfile
export ftn15=collisionfile
export ftn16=outputfile_with_decaying_resonances
export ftn19=outputfile_for_OSCAR97
export ftn20=outputfile_for_OSCAR99
urqmd.$(uname -m)
```

4.1 UrQMD at LHC energies

Please Note: Use of **UrQMD** at energies higher than RHIC energies is highly not recommended. Do so at your own risk!

To use **UrQMD** at LHC energies, compile the program with make lhc. This will create a binary named `urqmd.ARCH.lhc`.

Listing 2: sample input file for **UrQMD**

```
# this is a sample input file for urqmd
#   Ap  Zp
pro 197 79   # projectile (here: gold nucleus)
# optional: special projectile: ityp, iso3 (here: pi plus meson)
# PRO 101 2
#   At  Zt
tar 197 79   # target (here: gold nucleus)
nev 10       # number of events
tim 200 200  # time to propagate and output time-interval (in fm/c)
elb 160.0    # incident beam energy in AGeV
imp -3.0     # weighted impact parameter distribution (from 0-3 fm)
eos 0        # Equation of State (used in transport part): CASCADE mode
#   some options and parameters
cto 4  1     # output of initialization
ctp 1  1.d0  # scaling for decay width of Resonances
f15          # no output to file15
#  end of file
xxx
```

5 The input file

Listing 2 shows a typical input file for **UrQMD**. The general format of the input file is `(1A3,1A77)`. This means that every input line consists of two sections: First a three character flag followed by a 77 character string, the contents of which varies according to the flag specified. A sample input file (`inputfile`) is included.

The directives in the input file are unordered. However, it is mandatory that the input either contains definitions for projectile, target, impact parameter and incident beam energy or definitions for infinite matter calculation.

5.1 Input Parameters

These are possible input labels in **UrQMD** with their respective arguments. See Table 3 for an overview and Listing 2 for a sample input.

Table 3: Overview of all the possible input file flags

label	arguments	description
#	(none)	comment line
xxx	(none)	last line of input–file
pro	`Ap Zp`	define projectile
PRO	`ityp iso3`	define special projectile
tar	`At Zt`	define target
TAR	`ityp iso3`	define special target

(continued on next page)

Table 3 – continued from previous page

label	arguments	description
nev	`nevents`	number of events to calculate
tim	`tottime outtime`	define time of calculation and output
ene	`ebeam`	incident kinetic beam energy (lab frame)
elb	`ebeam`	alias for *ene*
plb	`pbeam`	incident beam momentum (lab frame)
PLB	`pmin pmax npbin`	incident (min/max) beam momentum for excitation function
PLG	`pmin pmax npbin`	like *PLB*, log-weighted
ecm	`srt`	$\sqrt{s}$ for two particle collision
ENE	`srtmin srtmax nsrt`	incident min/max $\sqrt{s}$ for excitation function
ELG	`srtmin srtmax nsrt`	like *ENE*, log-weighted
imp	`bmax`	define impact parameter
IMP	`bmin bmax`	define impact parameter
eos	`EoS`	define equation of state
box	`dim edens solid para`	define box for infinite matter calculation
bpt	`ityp iso3 npart pmax`	define particle population for box-mode
bpe	`ityp iso3 npart`	like *bpt*, for given energy density
rsd	`seed`	seed for random number generator
stb	`ityp`	keep particle stable
cdt	`deltat`	Δt between full collision load
f13	(none)	suppress output to unit 13
f14	(none)	suppress output to unit 14
f15	(none)	suppress output to unit 15
f16	(none)	suppress output to unit 16
f19	(none)	suppress output to unit 19
f20	(none)	suppress output to unit 20
ctp	`index value`	set optional parameter in CTParam array
cto	`index value`	set option in CTOption array

5.2 Input file organization

```
#   string
xxx string
```

Lines staring with **#** are ignored and are intended for comments.

xxx marks the end of the input file. `string` should contain at least one blank. On some systems it might be necessary to add an additional empty line after the *xxx*.

5.3 Definition of colliding system

See Section 5.7 for definitions of infinite matter (box-) calculations.

```
pro A Z
tar A Z
PRO ityp iso3
TAR ityp iso3
imp b
imp -bmax
IMP bmin bmax
```

pro defines the projectile as a nucleus with mass number `A` and charge `Z`

tar like *pro*, but for target.

PRO defines the projectile as special non-composite particle of the species defined by ityp `ityp` and iso3 (see Section 1.2). For a list of available itypes, see Tables 1 and 2.

TAR like *PRO*, but for target.

imp with a positive argument `b`: fixes the impact parameter of the collision at `b`. With a negative argument `-bmax`: choose impact parameter in the range from 0 to `bmax`.

IMP choose impact parameter in the range from `bmin` to `bmax`.

By default, the impact parameter is weighted quadratically. However, `CTOption(5)` can be used to change the weighting characteristic to linear weighting (**Please Note:** this is in contrast to the usual experimental trigger conditions). See Table 5 for more details on `CTOption(5)`.

A minimum bias calculation (including events without interaction!) can be performed with `bmin`=0, `bmax` $> R_p + R_t$.

5.4 Energy definition

All energies and energy-like quantities are given in GeV (or AGeV, where applicable).

```
ene ebeam
elb ebeam
ecm srts
ENE srtmin srtmax steps
ELG srtmin srtmax steps
plb pbeam
PLB pmin pmax steps
PLG pmin pmax steps
```

ene Define kinetic energy of the projectile as $E_{\text{lab}}^{\text{kin}} = (A_p) \cdot$ `ebeam`.

elb Alias for *ene*

ecm Define center-of-mass-energy $\sqrt{s_{\text{NN}}} =$ `ecm` between projectile and target.

ENE Do excitation function calculations. Use `steps` different energies, starting from $\sqrt{s_{\rm NN}} =$ `srtmin` and going up **linearly** to $\sqrt{s_{\rm NN}} =$ `strmax`.

ELG Do excitation function calculations. Use `steps` different energies, starting from $\sqrt{s_{\rm NN}} =$ `srtmin` and going up **logarithmically** to $\sqrt{s_{\rm NN}} =$ `strmax`.

plb Define momentum of the projectile as $p_{\rm lab} = (A_p) \cdot$ `pbeam`.

PLB Do excitation function calculations. Use `steps` different energies, starting from $p_{\rm lab} =$ `pmin` and going up **linearly** to $p_{\rm lab} =$ `pmax`.

PLG Do excitation function calculations. Use `steps` different energies, starting from $p_{\rm lab} =$ `pmin` and going up **logarithmically** to $p_{\rm lab} =$ `pmax`.

For fixed momentum/energy calculations, the lower-case flags *ene*, *elb*, *ecm* and *plb* are used, for excitation functions the upper-case flage *ENE*, *ELG*, *PLB* and *PLG* are needed. The binning of the excitation function is linear for *ENE* and *PLB* and logarithmic for *ELG* and *PLG*.

In the case of an excitation function calculation, the number of events `nev` refers to the **full** excitation function, i.e. the number of events per bin would be `nev`/`steps`.

Only one of the above seven definitions must be given. Make sure to only use one of the above commands for the beam energy in order to avoid ambiguities in the input file.

5.5 Calculation amount

```
nev numberofevents
tim tottime outtime
```

nev Defines the total number of events to calculate (see the comment in Section 5.4 about excitation function calculations) to be `numberofevents`.

tim Defines the calculation time: Particle list output will happen every `outtime` fm/c, the calculation will stop after `tottime` fm/c.

5.6 Physics assumptions

```
eos EoS
cdt deltat
stb ityp
```

eos Choose an Equation of State for the calculation. Currently only CASCADE mode (no potentials, `EoS`=0) or a hard Skyrme equation of state (`EoS`=1) are available. The default mode is CASCADE, the hard Skyrme equation of state is limited to incident beam-energies below 4.0 GeV/nucleon.

Please Note: This option also changes the initialization mode (see `CTOption(24)` in Table 5). **Please Note:** this option has nothing to do with the equation of state during the fluid-dynamic evolution in hybrid mode. See `CTOption(47)` for that.

cdt Force the collision and particle table update interval to `deltat`. In CASCADE mode a regular full particle scan for the collision arrays is not necessary, therefore this command should be only used in calculations including potentials, infinite matter calculations or for debugging purposes.

stb Set particle species with ityp `ityp` (see Tables 1 and 2 for available itypes) as stable particles. This parameter can be given multiple times, but no more than 20 times (this number is defined as maxstables in file `options.f`).

5.7 Infinite matter (box) calculations

```
box dim totenergy solid para
bpt ityp iso3 npart pmax
bpe ityp iso3 npart
```

box Start box calculations. Use a cubic box with a width of `dim` fm, a total energy content of $E_{\rm tot}$ = `totenergy` GeV. Use `solid`=0 for periodic boundary conditions (particles that hit the wall are inserted at the opposite wall) or `solid`=1 for reflecting walls. Use `para`=1 for "old" periodic boundary conditions.

bpt Fill box with `npart` particles of ityp `ityp` and iso3 `iso3` (see Section 1.2). Limit the fermi-sphere in momentum space to a maximum momentum of $p_{\rm max}^{\rm fermi}$ = `pmax` GeV.

bpe Fill box with `npart` particles of ityp `ityp` and iso3 `iso3`.

Please Note: only 20 different *bpt*/*bpe* statements can be given to **UrQMD**. If more are given, **UrQMD** will complain and fail, giving a description on how to raise that limit.

5.8 Numerics

```
rsd seed
f13
f14
f15
f16
f19
f20
```

rsd set (integer) seed for random number generator to `seed`. On many computer systems, **UrQMD** is able to extract a random seed from the local time at intervals of one second. However, we advise to check if this is indeed the case for your system. Especially, if running many **UrQMD** jobs in parallel or running very small jobs (that may take less than one second to complete), it is recommended to set different individual seeds to avoid synchronisation of the runs due to the same start time.

Advice: If you create the input files for **UrQMD** on UNIX-like systems automatically, you may obtain high-quality random numbers with $(printf '%d' 0x$(xxd -l 3 -ps -c 10 /dev/urandom))

Please Note: Giving a negative seed is tantamount to not setting this directive at all.

f13,f14,... Suppress output to the respective files (see Section 6)

5.9 Special options/parameters

```
ctp index value
cto index value
```

ctp Set special parameter `CTParameter(index)=value`. See Table 4.

cto Set special option `CTOption(index)=value`. See Table 5.

Please Note: if you are running **UrQMD** from an old event output via `CTOption(40)` $\neq 0$, please refer to Section 6.7 for further information.

Please Note: if `CTOption(45)=1` is used the code needs 2GB of memory because of the dimensions of the fluid-dynamic grid and the corresponding array sizes.

Table 4: Optional parameters for **UrQMD**

CTP	default	explanation
1	1.d0	scaling factor for resonance widths
2	0.52d0	minimal stringmass and elastic/inelastic cut
3	2.0d0	velocity exponent for modified AQM
4	0.3d0	transverse pion mass, used in `make22`
5	0.0d0	probability for quark rearrangement in cluster
6	0.37d0	strangeness probability in strings
7	0.d0	charm probability (not yet implemented in **UrQMD**)
8	0.093d0	probability to create a diquark
9	0.35d0	kinetic energy cut-off for last string break
10	0.25d0	min. kinetic energy for hadron (in string)
11	0.0d0	percentage of non groundstate resonances (in string)
21	0.d0	deformation parameter
25	0.9d0	probability for diquark not to break
28	1.d0	scaling factor for transverse fermi motion
29	1.d0	double strange di-quark suppression factor
30	1.5d0	radius offset for initialization
31	1.6d0	σ of Gaussian for transverse momentum transfer
32	0.d0	$\alpha - 1$ for valence quark distribution
33	2.5d0	β_v for valence quark distribution
34	0.1d0	minimal x multiplied with $E_{c.m.}$

(continued on next page)

Table 4 – continued from previous page

CTP	default	explanation
35	3.0d0	offset for cut for the FSM
36	0.275d0	fragmentation function parameter a (nucleons)
37	0.42d0	fragmentation function parameter b (nucleons)
38	1.08d0	diquark p_t scaling factor
39	0.8d0	strange quark p_t scaling factor
40	0.5d0	$\beta_s - 1$ for valence quark distribution
41	0.d0	distance between nuclei at initialization
42	0.55d0	width of Gaussian for p_t-distribution in string-fragmentation
43	5.0d0	maximum kinetic energy in mesonic cluster
46	8.0d6	maximum number of rejections during initialization of nuclei
47	1.0d0	Field-Feynman fragmentation func. parameter a (prod. part.)
48	2.0d0	Field-Feynman fragmentation func. parameter b (prod. part.)
49	0.5d0	additional single strange diquark suppression factor
50	1.0d0	enhancement factor for 0^{-+} mesons
51	1.0d0	enhancement factor for 1^{--} mesons
52	1.0d0	enhancement factor for 0^{++} mesons
53	1.0d0	enhancement factor for 1^{++} mesons
54	1.0d0	enhancement factor for 2^{++} mesons
55	1.0d0	enhancement factor for 1^{+-} mesons
56	1.0d0	enhancement factor for $(1^{--})^*$ mesons
57	1.0d0	enhancement factor for $(1^{--})^{**}$ mesons
58	1.0d0	scaling factor for DPF time-delay
59	0.7d0	scaling factor for leading hadron cross-section (PYTHIA)
60	3.0d0	resonance/string transition energy for s-channel
61	0.2d0	cell size dx in the fluid description
62	200	number of cells per dimension of the fluid grid $N_{\rm gr}$
63	1.0d0	minimum $t_{\rm start}$ for fluid calculation
64	5.0d0	multiplied with ϵ_0 as particlization criterion
65	1.0d0	factor to be multiplied with $t_{\rm start}$
66	1.d10	rapidity cut for fluid-dynamical description
67	1.d0	integer number of testparticles per real particle
68	1.d0	width of 3d Gaussian density calculations at fluidization
69	0.d0	quark density cut for fluidization (core-corona separation) $[1/(3\rho_0)]$ [12]

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Table 4 – continued from previous page

CTP	default	explanation
70	1.d10	cut in pseudorapidity used to calculate the core density at fluidization
71	2.d0	timestep interval for construction of the hypersurface
72	0.55d0	Ratio of $\Sigma^0/(\Sigma^0+\Lambda^0)$ in $K+N\to\pi+Y$ in strangeness exchange

Table 5: Options for **UrQMD**

CTO	default/ options	description
1	0	mass dependent resonance decay widths
	0	enabled
	1	disabled
2	0	2-particle scattering plane:
	0	stochastic selection of $\varphi(1,2)$
	1	conserve plane
3	0	detailed balance selection
	0	take finite resonance widths into account
	1	use standard detailed balance
4	0	initial configuration output to 14
	0	output according to `tim` statement
	1	**additional** output of initialization
5	0	impact parameter weighting
	0	use `bmax` as fixed impact parameter
	1	random b from `bmin` to `bmax`, bdb weighted
	2	random b from `bmin` to `bmax`, flat distribution
6	0	first collisions within target/projectile
	0	block first collisions **within** proj./target
	1	all collisions allowed
7	0	suppress elastic NN collisions
	0	elastic collisions are allowed
	1	no elastic NN collisions; $\sigma_{in}=\sigma_{tot}$

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Table 5 – continued from previous page

CTO	default/ options	description
8	0	mass dependent partial decay widths
	0	enabled
	1	disabled, use fixed widths
9	0	tabulated p+p inelastic cross sections
	0	enable table-lookup
	1	disable table-lookup
10	0	Pauli-blocker
	0	enable Pauli-blocker
	1	disable Pauli-blocker
11	0	mass reduction (binding energy) in CASCADE mode
	0	enable mass reduction according to binding energy
	1	disable mass reduction
12	0	string production
	0	enable string production
	1	disable string production
13	0	enhanced 16 output
	0	disabled
	1	enabled
14	0	angular distribution in binary scattering
	0	enable angular distribution
	1	disable distribution ($\cos(\vartheta) = 1$ forward peak)
15	0	meson-meson and meson-baryon scattering
	0	enable MM and MB scattering
	1	disable MM and MB scattering
16	0	molecular dynamics switch
	0	enable collision term
	1	propagate with forces only (disable collision term)
17	0	collision-table update mode
	0	update only collision partners after interaction
	1	initialize complete table after every interaction

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Table 5 – continued from previous page

CTO	default/ options	description
18	0	decay of unstable particles at end of event
	0	perform decay after final timestep
	1	unstable particles do not decay after final timestep
19	0	$B\bar{B}$ annihilation
	0	enabled
	1	disabled
20	0	e^+e^- annihilation instead of $B\bar{B}$ annihilation
	0	disabled (normal $\bar{B}B$ mode)
	1	enabled (e^+e^- mode)
21	0	string fragmentation function
	0	field-Feynman fragmentation function
	1	Lund fragmentation function
	2	QGSM fragmentation function
22	1	string mass excitation
	-1	simple $1/M$ excitation
	1	FRITIOF ansatz
	2	QGSM ansatz
23	0	Lorenz contraction of projectile and target
	0	enabled
	1	disabled
24	1	initialization mode
	0	hard sphere (used for EOS$\neq$0)
	1	Woods-Saxon (used for CASCADE mode)
	2	Fast Woods-Saxon (used for CASCADE mode)
25	0	phase space correction for resonance masses
	0	disabled
	1	enabled

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Table 5 – continued from previous page

CTO	default/ options	description
27	0	reference frame for calculation
	0	N.N. (equal speed) frame
	1	target (lab) frame
	2	projectile frame
29	2	p_t for last two particles in string (`clustr`)
	0	isotropic
	1	isotropic, baryon goes into forward hemisphere
	2	baryon goes into forward hemisphere, $p_t = 0$
30	1	frozen Fermi approximation in CASCADE mode
	0	disabled
	1	enabled
32	0	distribute resonance masses according to mass-dep. Breit-Wigner
	0	enabled
	1	disabled
33	0	use table-lookup for calculation of $\langle p_{CMS} \rangle$ in `pmean`
	0	enabled
	1	disabled
34	1	resonance life-times
	0	$\tau = 1/\Gamma(M)$
	1	$\tau = 1/\Gamma_{pole}$
	2	DPF formalism
35	1	generate high-precision tables (file `tables.dat`)
	0	disabled
	1	enabled
36	0	correct normalization for mass-dependent Breit-Wigner distributions
	0	enabled
	1	disabled
37	0	heavy quark clusters
	0	disabled
	1	enabled

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Table 5 – continued from previous page

CTO	default/ options	description
38	0	scale p-pbar to b-bbar with equal p_lab instead of equal $\sqrt{s}$
	0	disabled
	1	enabled
39	0	compute collision densities via call to Pauli-blocker
	0	enabled
	1	disabled
40	0	use old fort.14 as initial state for calculation. Set file fort.10
	0	disabled
	1	enabled: set all `CTOption()` and `CTParameter()` to the values in fort.10
	2	enabled: only set options/parameters marked with asterisk.
41	0	extended fort.14 output (needed for `CTOption(40)`)
	0	disabled
	1	enabled
	2	different counting rules for origin
42	0	color fluctuations in high energy hadron-hadron collisions
	0	disabled
	1	enabled
44	1	Pythia call for hard scatterings
	0	disabled
	1	enabled
45	0	Hydro mode (**Please Note:** high memory requirement!)
	0	disabled
	1	enabled
46	0	Density calculation switch
	0	ρ_B
	1	$\rho_{q+\bar{q}}$
47	5	EoS for fluid-dynamical evolution
	2	hadron gas (HG)
	3	bag model (BM)
	5	chiral+hadron gas incl. deconfinement (DE)

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Table 5 – continued from previous page

CTO	default/ options	description
48	0	number of timesteps for fluid-dynamical propagation
	0	usual run until particlization
	N	forced particlization after N timesteps
49	0	Spectator switch
	0	spectators are propagated in **UrQMD**
	1	spectators are propagated as part of the fluid
50	0	(Additional) CTO 14/CTO 19-output directly after particlization
	0	disabled
	1	enabled
52	0	Particlization model for fluid
	0	Gradual particlization scenario (GF)
	1	Isochronuous particlization
	2	Iso-energy density hypersurface
53	0	Improved momentum generation in Cooper-Frye
	0	enabled
	1	disabled
54	0	OSCAR 2008H output during fluid-dynamical evolution
	0	disabled
	1	enabled (full evolution)
	2	enabled (hyper surface)
55	0	OSCAR 1997A output adjusted for visualization **Please Note:** see Section 6.6.1
	0	disabled
	1	enabled
56	0	Toggle behaviour of first field in Collision history file CTO 15
	0	Old behaviour with slot ID (internal number)
	1	Unique particle ID (specific to this particle)
57	1	print complete event header
	0	legacy format with `CTOption(1..45)` and `CTParameter(1..48)`
	1	complete format with currently 60 `CTOption()` and 72 `CTParameter()`.

(continued on next page)

Table 5 – continued from previous page

CTO	default/ options	description
58	0	control event header in collision history file ◯●○15
	0	abbreviated event header
	1	standard event header in ◯●○15 like in the other files.
59	0	Inclusion of $\Lambda/\Sigma + \Lambda/\Sigma \leftrightarrow \Xi + N$ strangeness exchange reactions
	0	Process is turned off
	1	Process is turned on

6 Output files

UrQMD provides several different outputs. Please refer to Section 5.8 on how to turn them on and off. All outputs are named after their FORTRAN file handles, i.e., fort.13 ... fort.20. You can set the file names by setting the respective environment variables ftn13 ... ftn20 to the desired file names, see Listing 1 on page 7.

standard output files (fort.13 and fort.14, Section 6.3): contain all particles of a given event at a certain time-step.

collision history file (fort.15, Section 6.4): contains information on all collisions, decays and similar events.

decay file (fort.16, Section 6.5): contains information on all decayed particles and stable particles after final timestep of a given event.

OSC files (fort.19, fort.20, fort.f21 Section 6.6): generates output compliant with the Open Standards And Codes (OSCAR) format.

Each run of **UrQMD** creates one file of each activated output. If more than one event is calculated, the outputs for each event are written to the same file sequentially. The output for each event consists of a header and a body. The fort.f21 file for hydro visualization is an exception. Here, a new file will be created if the grid size changes during the hydro run. Each new file is named with a number increased by three in the file extension, e.g. fort.f21, fort.f24, fort.f27, ...

6.1 Standard event header

Output files fort.13, fort.14 and fort.16 (as well as fort.15 with `CTOption(58) = 1`) each write one detailed event header per event. That header consists of more than 9 lines, *each starting with a letter*. The lines are formatted as follows:

1. format `(a20,3i7,a15,i2)`
2. format `(a13,a13,i4,i4,a12,a13,i4,i4,a1)`
3. format `(a36,3f11.7)`
4. format `(a36,3f6.2,a31,1f9.2)`
5. format `(a20,i3,a15,e11.4,a15,e11.4,a15,e11.4)`
6. format `(a7,i9,a13,i12,a9,a20,i7,a20,f11.3)`
7. $n\times$ format `(a2,15(i3,a2))`
8. $m\times$ format `(a2,12(e11.4,a2))`
9. format `(a171)`

Here, n is the number of lines with `CTOption()` output and m is the number of lines with `CTParameter()` output. In versions prior to 3.4, $n = 3$ and $m = 4$. In Version 3.4, $n = 4$ and $m = 6$ unless `CTOption(57)` is set to 0. The lines `CTOption()`-lines specified in item 7 all start with the characters “op”, while the `CTParameter()`-lines specified in item 8 all start with the caracters “pa”. The line specified in item 9 starts with the characters “pvec”.

context	format
13	format (9e16.8,i11,2i3,i9,i5,i4,8e16.8)
standard 14 and 16	format (9e16.8,i11,2i3,i9,i5,i4)
14 + CTOption(**41**)=1	format (9e16.8,i11,2i3,i9,i5,i10,3e16.8,i8)
15	format (i5,9e16.8,i11,2i3,i9,i5,i3,i15)
16 + CTOption(**13**)=1	format (9e15.7,i11,2i3,i9,i5,i4,2i4)

Table 6: Formats for particle vectors in different output contexts

The contents of the header are largely self-explanatory and contain all relevant information about the current event that can be obtained. A sample header is shown in Listing 3 on Page 30. In it, all alphabetic characters are fixed, only the numbers may change. Note that in lines 7 – 13, where the current options and parameters are printed, an asterisk ('*') will be added behind any option/parameter that is altered.

In infinite matter calculation mode (see Section 5.7), output to 14 contains additional lines to specify information on the box.

Listing 4 contains a sample box header. The format of the box header lines is

1. format (a20,e14.6,a20,e14.6,a3,i1,a3,i1,a3,i3)
2. format (a35)
3. format (a5,2i4,i8,e14.6)

All lines of the box-header are guaranteed to start with 'box'. The first line contains the word 'boxmode', followed by length of the box, total energy, the parameters solid and para (see Table 3) and the number of specified particle species N. The second line (starting with 'boxh') contains no physical information. The rest of the box-header contains N lines, each of them stating ityp, iso3, number and maximal momentum of the particles as specified in the *bpt* and *bpe* input file directives.

6.2 Particle vector

A "particle vector" is one line of output which contains information about one particle. Depending on the active output and chosen CTOption()s, the information in this line can differ. Table 6 shows an overview of the different possible FORTRAN formats.

The contents of the different particle vectors is listed in Table 7. All reference frame dependent values are given in the computational frame, which has been fixed by CTOption(**27**). All time outputs are given in $[t] = 1$ fm/c, all coordinate outputs are given in $[r] = 1$ fm, energies are given in $[E] = 1$ GeV, momenta in $[p] = 1$ GeV/c and masses in $[m] = 1$ GeV/c^2. **Please Note:** the index of a particle (column 1 and 15 in 15, column 13 in 13, 14 and 16, column 19 in 14 with CTOption(**41**)) are **not** suited to track a special particle and are only constant at the exact time of that particular output.

filehandle	13	14	15	16	**contents**
			1		ind: index of particle (see `CTOption(56)`)
	1	1	2	1	t: time of particle
	2	2	3	2	r_x: x coordinate
	3	3	4	3	r_y: y coordinate
	4	4	5	4	r_z: z coordinate
	5	5	6	5	E: energy of particle
	6	6	7	6	p_x: x momentum component
	7	7	8	7	p_y: y momentum component
	8	8	9	8	p_z: z momentum component
	9	9	10	9	m: mass of particle
	10	10	11	10	ityp: particle-ID
	11	11	12	11	iso3: $2 \cdot I_3$ (see Section 1.2)
	12	12	13	12	ch : charge of particle
	13	13	14	13	parent collision number (see Table 10)
	14	14	15	14	N_{coll} number of collisions
			16		S : strangeness
	15	15		15	parent process type (see Table 11)
			17		history information (debugging only)
	16				t^{fr} : freeze-out time of particle
	17				r_x^{fr} : freeze-out x coordinate
	18				r_y^{fr} : freeze-out y coordinate
	19				r_z^{fr} : freeze-out z coordinate
	20				E^{fr} : freeze-out energy of particle
	21				p_x^{fr} : freeze-out momentum x component
	22				p_y^{fr} : freeze-out momentum y component
	23				p_z^{fr} : freeze-out momentum z component
		16*			τ_{dec} decay time of particle
		17*			τ_{form} formation time of particle
		18*			R_σ cross section reduction factor
		19*			unique particle number (not ID!)
				16*	$\mathrm{ityp}_1^{\mathrm{old}}$: particle-ID of parent particle # 1
				17*	$\mathrm{ityp}_2^{\mathrm{old}}$: particle-ID of parent particle # 2

Table 7: Contents of the particle vectors in the **UrQMD** output files. Outputs that are only available with extended output options (`CTOption(41)` for 14 and `CTOption(13)` for 16) are marked with an asterisk *.

column#	contents
0	"E" (only in o16)
1	# of collisions
2	# of elastic collisions
3	# of inelastic collisions
4	# of Pauli-blocked collisions
5	# of decays
6	# of produced *hard* baryon resonances
7	# of produced *soft* baryon resonances
8	# of baryon resonances produced via a decay of another resonance

Table 8: description of the collision/decay counters in the standard output file body. All fields are 8 characters wide integers `(i8)`, except the first in o16, which is `(a1)`.

6.3 Standard output files: o13/o14

The standard output files contain the phase-space of the event at a given time (e.g. final output after last timestep). o13 contains the same information as o14, but additionally lists the freeze-out coordinates (i.e. coordinates of last interaction) in configuration- and momentum-space for all particles.

Consecutive timesteps and events are added sequentially to the files, but the event header is not repeated.

The header for o13 and o14 is the standard event header as described in Section 6.1 and Listing 3. In the case of running **UrQMD** in box mode, o14 contains additional header lines reporting the box-related parameters, see also Listing 4.

The standard output file body (see Listing 5) then consists of $N_{\rm ev}$ chunks of $N_{\rm part}+2$ lines each, where $N_{\rm part}$ is the number of particles at the time of output:

1. Number of particles $N_{\rm part}$ to follow and time of output (two unformatted integers).
2. Collision counter line (see below)
3. Particle vector (see below)
4. ...

The collision counter line contains counters for the number of collisions, decays and produced resonances per event (format `(8i8)`), see Table 8.

The subsequent N_{part} lines contain the information on the individual particles. The exact format of the particle vector depends on the output file and the selected options. See Section 6.2 for details on the particle vector.

For comparisons to experimental data, the standard output files should suffice, since they can give the final particle spectra at the last time step.

column#	format	**contents**
1	`(i8)`	fixed number "-1"
2	`(i8)`	event counter
3	`(i4)`	mass number of projectile (A_p)
4	`(i7)`	mass number of target (A_t)
5	`(f8.3)`	impact parameter b of event in fm
6	`(e12.4)`	center of mass of the heavy-ion collision $\sqrt{s_{\rm NN}}$ in GeV
7	`(e12.4)`	total cross-section of the heavy-ion collision $\sigma_{\rm tot}$ in mbarn
8	`(e12.4)`	beam energy of the projectile $E_{\rm lab}$ in AGeV
9	`(e12.4)`	beam momentum of the projectile $p_{\rm lab}$ in AGeV/c

Table 9: Formats and contents of the shortened event header as used in output files 15.

6.4 Collision history file: 15

The collision file 15 contains each binary interaction, resonance decay and string-excitation which occurred in the course of the heavy-ion reaction. For calculations with fluid-dynamic phase, it also contains all particles at fluidization and all particles at particlization (also spectators are listed). For infinite matter calculations, all interactions with the wall are also itemized. It can be used to reconstruct the entire space-time evolution of the event.

The event header used in 15 is a one-line short summary of the collision parameters, unless `CTOption(58)` = 1 (for that case, the standard event header is written, see Section 6.1). The fields of the event header and their formats can be found in Table 9.

The body consists of one or more collision entries (depending on the number of ocurrences during the event), all of which have one collision header and a certain number of particle vector lines (for the particle vector, please refer to Section 6.2), depending on the number of particles involved. The collision header has the same formats as the event header, but different contents. The two can be **distinguished** by the **first entry**: If it is $= -1$, the line is a event header, if it is $>= 0$, the line is a collision header. The fields of the collision header and their formats can be found in Table 10. Special combinations of the first two fields $N_{\rm in}$ (number of ingoing particles) and $N_{\rm out}$ (number of outgoing particles) include:

1,1 wall interaction (infinite matter calculations)
1,$N > 1$ decay
2,1 annihilation
2,2 scattering
2,$N > 2$ string excitation and decay
1,0 Pauli-blocked decay
2,0 Pauli-blocked scattering
N**,0** Fluidization: All particles at the beginning of the fluid-dynamical part (Process-ID "91"). **Please Note:** this also includes spectators and corona-particles that are not transferred to the fluid!

column#	format	**contents**
1	`(i8)`	number of ingoing particles $N_{\rm in}$
2	`(i8)`	number of outgoing particles $N_{\rm out}$
3	`(i4)`	process ID (see Table 11)
4	`(i7)`	collision/entry counter
5	`(f8.3)`	collision time $t_{\rm coll}$ in fm/c
6	`(e12.4)`	center of mass energy of the collision $\sqrt{s}$ in GeV
7	`(e12.4)`	total cross-section of the collision $\sigma_{\rm tot}$ in mbarn
8	`(e12.4)`	partial cross-section of the actual sub-process $\sigma_{\rm i}$ in mbarn
9	`(e12.4)`	Baryon density at collision point $\rho_{\rm B}$ in units of ρ_0

Table 10: Formats and contents of the collision header as used in outputs 15 and OSCAR 1999A. See text for possible values of in- and outgoing particle number values. **Please Note:** not all fields need to be defined in each given type of entry and thus may be "NaN" or meaningless.

0;N Particlization: All particles at the end of the fluid-dynamical part (Process-ID "96"). Here, $t_{\rm coll}$ is set to the end of the overall fluid-dynamical evolution. The actual emission time of each particle differs for gradual particlization (see `CTOption(52)`). Particles that have not been part of the fluid (cascade propagation of spectators (see `CTOption(49)`) and/or core-corona separation (see `CTParameter(69)` and `CTParameter(70)`)) are listed with their original parent process IDs, while all others have their parent process ID set to "96".

The collision header is followed by $N_{\rm in} + N_{\rm out}$ particle vectors (see Section 6.2), listing first the ingoing and then the outgoing particles.

One of the purposes of the collision file is to have the possibility to track the trajectory of a single particle in the course of the reaction or the time evolution of the available center of mass-energy per binary collision.

6.5 Decay output file: 16

The decay output file 16 lists all particles that have either decayed during the event or are still present at the end of the event. The event header used is the standard event header as discussed in Section 6.1.

The body of the decay file contains one particle vector for each decay (itemizing the decaying particle at the decay) and each stable particle and is terminated by a line itemizing statistics on this event (since this file is written sequentially, it is impossible to obtain this information at the beginning of output). The termination line starts with the letter "E", followed by the collision counter also used in the standard output files, see Table 8.

For `CTOption(13)` = 1, all outgoing particles of all collisions and decays are listed instead of the decaying particles alone. The *decay output file* provides additional information about the produced

Process ID#	Description
1	$NN \to N\Delta$
2	$NN \to NN^*$
3	$NN \to N\Delta^*$
4	$NN \to \Delta\Delta$
5	$NN \to \Delta N^*$
6	$NN \to \Delta\Delta^*$
7	$NN \to N^*N^*, N^*\Delta^*, \Delta^*\Delta^*$
8	$N\Delta \to \Delta\Delta$
10	$MB \to B'$
11	$MM \to M'$
13	BB (but not pp or pn) elastic scattering
14	inelastic scattering (no string excitation)
15	$BB \to$ 2 strings
17	pn elastic
19	pp elastic
20	decay
22	$B\bar{B}$ elastic
23	$B\bar{B}$ annihilation $\to$ 1 string
24	$B\bar{B}$ diffractive $\to$ 2 strings
26	MB elastic scattering
27	$MB, MM \to$ 1 string
28	$MB, MM \to$ 2 strings
30	$N\Delta \to NN$
31	$\Delta\Delta \to \Delta N$
32	$\Delta\Delta \to NN$
35	$N\Delta$ inelastic
36	Danielewicz forward delay ($MB \to B'$)
37	Danielewicz forward delay ($MM \to M'$)
38	MM elastic scattering
39	$B\bar{B}$ inelastic scattering (no annihilation)
80	Periodic wall: Particle crosses the box wall
81	Solid wall: Particle reflects off the box wall
91	Fluidization
96	Particlization

Table 11: list of process identifiers

baryon- and meson-resonances when compared to the *standard output file*. Since it contains particle output at different times during the event, however, one has to be very careful when extracting cross-sections.

6.6 OSCAR outputs

The OSC output format has been defined by the OSCAR group in order to create a well-defined, easily accessible output-format which is supported by all OSCAR compliant transport models, event generators and other heavy-ion related models. In this Section, we describe the OSCAR output produced by **UrQMD** and dispense with all the possibilities defined by the OSCAR group. For a full overview of the goals of the OSCAR collaboration, please consult the web-site

`http://karman.physics.purdue.edu/OSCAR/`

Output in OSCAR format always uses the PDG HEP particle IDs accoring to [9]. Composite clusters (nuclei) are marked with a seven-digit number calculated from $P = 7,000,000+1,000A+Z$, where A is the mass number of the nucleus and Z is its charge. The definition of the colliding system is given as "$(A_p, Z_p), (A_t, Z_t)$", where the index p refers to the projectile and t refers to the target. If objects other than nuclei are used as projectile or target, the mass is given as "-1" and the charge is replaced by the PDG-ID.

6.6.1 OSCAR 1997A format: o19

UrQMD supports the **OSC1997A** output format on o19. The output consists of a file header, an event header and particle vector lines.

The file-header consists of three lines:

1. Specifies output format (i.e., "`OSC1997A`")
2. File contents (i.e., "`final_id_p_x`")
3. General information, see Table 12

The file body consists of a one-lined event header (see Table 13) and subsequent particle vector lines (see Table 14). The first field in OSCAR 1997A particle vector lines is a simple counter that enumerates the particles in this particular output. This number does not correspond to any number in any other output.

Listing 8 shows a sample output in the OSCAR 1997A format. **Please Note:** the output on o19 is not OSCAR-conformant if `CTOption(55)`=1!

6.6.2 OSCAR 1999A format: o20

The **OSC1999A** is an improvement to the **OSC97A** output and allows to write out the complete event history – starting with the initial state, including all binary collisions, string-fragmentations and hadronic decays. In its scope it is comparable to the **UrQMD** collision history output file (o15), but it includes also the full initial configuration and final state information.

As in the case of the **OSC1997A** output, the **OSC1999A** output consists of a file header and a body, which in turn consists of an event header and an event body. The file header is similar to the

Listing 3: sample standard header

```
UQMD   version:        30040    1000   30040   output_file   14
projectile:  (mass, char)  208    2    target:  (mass, char)  208    2
transformation betas (NN,lab,pro)        0.0000000  0.9561610 -0.9561610
impact_parameter_real/min/max(fm):      0.00   0.00   0.00   total_cross_section(mbarn):          0.00
equation_of_state:     0   E_lab(GeV/u): 0.2000E+02   sqrt(s)(GeV): 0.6406E+01   p_lab(GeV/u): 0.2092E+02
event#           1 random seed:   1330951098 (auto)    total_time(fm/c):        200 Delta(t)_O(fm/c):         200.000
op  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
op  0     0     0     0     0     0     1     0     1     0     0     0     0     2     1
op  0     0     0     1     1     0     0     0     0     0     0     0     0     1     0
pa 0.1000E+01    0.5200E+00    0.2000E+01    0.3000E+00    0.0000E+00    0.3700E+00    0.0000E+00    0.9300E-01    0.3500E+00    0.2500E+00    0.0000E+00    0.5000E+00
pa 0.2700E+00    0.4900E+00    0.2700E+00    0.1000E+01    0.1600E+01    0.8500E+00    0.1550E+01    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
pa 0.9000E+00    0.5000E+02    0.1000E+01    0.1000E+01    0.1000E+01    0.1500E+01    0.1600E+01    0.0000E+00    0.2500E+01    0.1000E+00    0.3000E+01    0.2750E+00
pa 0.4200E+00    0.1080E+01    0.8000E+00    0.5000E+00    0.0000E+00    0.5500E+00    0.5000E+01    0.8000E+00    0.5000E+00    0.8000E+06    0.1000E+01    0.2000E+01
pvec: r0              rx              ry              rz              p0              px              py              pz              m          ityp 2i3 chg lcl#   ncl  or
```

Listing 4: sample box header

```
boxmode length(fm):    0.200000E+02 tot. energy (GeV):    0.228900E+04 s:1 p:0 #:   1
boxh ityp 2i3        N      pmax(GeV)
box:   101    1     2289   0.763000E+03
```

Listing 5: standard file body

```
 83  60
      248      105      141        2       78      165        0        0
   .60000000E+02  -.35597252E+02  -.76801184E+01   .30121505E+01   .11839331E+01  -.70109432E+00  -.16633296E+00   .51512840E-01   .93800002E+00   1   1   1     1     9    20
   .60000000E+02   .81996126E+01   .19904670E+02  -.24104662E+02   .11707300E+01   .14606801E+00   .47854791E+00  -.49032721E+00   .93800002E+00   1  -1   0     2    17    20
   ...
   .60000000E+02   .54067910E+01   .30092770E+02   .35340946E+02   .15291829E+01   .14462310E+00   .74024320E+00   .94322867E+00   .93800002E+00   1   1   1    37     3    30
   .60000000E+02   .72953637E+00  -.35051235E+01  -.14941324E+02   .96631053E+00   .47106723E-02  -.60615381E-01  -.22408834E+00   .93800002E+00   1   1   1    13     2    19
```

Listing 6: collision history file excerpt. **Please Note:** the floating point values in the particle vectors have been abbreviated

```
      -1        1  208     208    0.000   0.6406E+01   0.0000E+00   0.2000E+02   0.2092E+02
       2        2   19       1    0.515   0.6555E+01   0.3880E+02   0.8439E+01   0.7304E+00
  90   0.51477E+00  -0.22396E+01  -0.14022E+01   0.21885E-01   0.29044E+01  -0.12325E+00  -0.15961E+00   0.27538E+01   0.90064E+00   1  -1   0     0     0   0           0
 337   0.51477E+00  -0.13037E+01  -0.16944E+01   0.21885E-01   0.37171E+01  -0.25111E+00   0.27756E-01  -0.36005E+01   0.88841E+00   1  -1   0     0     0   0           0
  90   0.51477E+00  -0.22396E+01  -0.14022E+01   0.21885E-01   0.29130E+01  -0.32506E+00  -0.65253E-02   0.27386E+01   0.93800E+00   1  -1   0   337     1   0         100
 337   0.51477E+00  -0.13037E+01  -0.16944E+01   0.21885E-01   0.37084E+01  -0.49300E-01  -0.12533E+00  -0.35853E+01   0.93800E+00   1  -1   0    90     1   0         100
       2        1   10      20    1.004   0.1643E+01   0.2696E+02   0.2583E+02   0.6155E+00
 432   0.10044E+01   0.58422E+00   0.60642E+00   0.17561E+00   0.17949E+00   0.45410E-01  -0.56387E-01   0.89063E-01   0.13800E+00 101  -2  -1 40008     1   0      1001015
 218   0.10044E+01   0.53143E+00   0.11509E+01   0.30243E+00   0.34864E+01   0.13197E+00  -0.34024E-03  -0.33608E+01   0.91776E+00   1   1   1     0     0   0           0
 218   0.10044E+01   0.55783E+00   0.87868E+00   0.23902E+00   0.36659E+01   0.17738E+00  -0.56727E-01  -0.32718E+01   0.16430E+01  17  -1   0   432     1   0      1101010
```

Listing 7: decay file body. **Please Note:** the floating point values in the particle vectors have been abbreviated

```
   0.1153063E+01  -0.8552205E+00   0.1698983E+01   0.4187249E+00   0.3107967E+01  -0.1776063E+00  -0.9330036E-01   0.2567548E+01   0.1739801E+01    17   1   1    -323     2     5
   0.1293414E+01   0.1492260E+01  -0.2571912E+01  -0.3650216E+00   0.3335035E+01   0.1174147E+00  -0.3825273E+00  -0.2917005E+01   0.1566340E+01    17  -1   0    -257     3    10
   ...
   0.2000000E+03   0.1384326E+02  -0.6462470E+00   0.1794777E+03   0.3309835E+00   0.3864880E-01  -0.6259776E-01   0.2917085E+00   0.1380000E+00   101   0   0    2507     1    20
   0.2000000E+03   0.1384326E+02  -0.6462470E+00   0.1794777E+03   0.1009709E+01   0.3227158E-01  -0.4587067E-01   0.9986609E+00   0.1380000E+00   101   0   0    2507     1    20
E     3802       951      2851         0      2022      2484         0         0
```

column#			
OSC97	**OSC99**	format	**contents**
1		`(a8,2x)`	name of the model (fixed to `UrQMD`)
2		`(a8,2x)`	version of the model
3	1	`('(',i3)`	mass number of projectile
4	2	`(',',i6)`	charge of projectile
5	3	`('),(',i3)`	mass number of target
6	4	`(',',i6,')')`	charge of target
7	5	`(2x,a4,2x)`	Reference frame ("pro"/"tar"/"eqsp": equal speed frame)
8	6	`(e10.4,2x)`	incident beam energy
9	7	`(i8)`	number of test-particles per nucleon

Table 12: Formats and contents of the 3$^{\text{rd}}$ line of the OSCAR 1997A file header and the 4$^{\text{th}}$ line of the OSCAR 1999A file header.

column#	format	**contents**
1	`(i10,2x)`	event counter
2	`(i10,2x)`	number of particles in event
3	`(f8.3,2x)`	impact parameter (in fm/c)
4	`(f8.3)`	rotation of the event plane (fixed to `0` in **UrQMD**)

Table 13: Formats and contents of the OSCAR 1997A event header.

Listing 8: excerpt from sample OSC1997A output

```
OSC1997A
final_id_p_x
   UrQMD  3.4-rc1  (208,      2)+(208,      2)  eqsp  0.2000E+02          1
         1        1451      0.000      0.000
         1        2212  0.409237E-01  -.125838E+00  -.211538E+01  0.231779E+01  0.938000E+00  -.273590E+01  -.688383E+01  -.478464E+02  0.560353E+02
         2        2212  0.249831E+00  0.793475E+00  0.809610E+00  0.149242E+01  0.938000E+00  0.312315E+01  0.475901E+01  0.771041E+01  0.190633E+02
       ...
      1450        -211  -.693173E-01  -.347416E-01  -.172573E+00  0.234174E+00  0.138000E+00  -.614586E+02  -.783037E+02  -.117446E+03  0.200000E+03
      1451        -211  -.373969E+00  0.755634E-01  -.805586E+00  0.901985E+00  0.138000E+00  -.871060E+02  -.583837E+02  -.123818E+03  0.200000E+03
```


Listing 9: excerpt from sample OSC1999A output

```
# OSC1999A
# full_event_history
# UrQMD 3.4-rc1
# (208,      2)+(208,      2)  nncm  0.2000E+02          1
      0      416        1     0.000      0.000
         1        2212          0  -.162903E+00  0.611857E-02  0.294178E+01  0.308730E+01  0.922381E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
         2        2212          0  0.219768E-01  0.269256E-01  0.350922E+01  0.363038E+01  0.929449E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
       ...
       415        2112          0  -.194555E+00  -.229860E+00  -.319714E+01  0.333189E+01  0.888285E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
       416        2112          0  0.115517E-01  -.224440E+00  -.324933E+01  0.338191E+01  0.910290E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
      2        5       15        1    0.355   0.6558E+01   0.3916E+02   0.2065E+02   0.3021E+00
       139        2112          0  -.938795E-01  -.558308E-01  0.286612E+01  0.301500E+01  0.929322E+00  0.591308E+00  -.141934E+01  0.492227E+00  0.354896E+00
       209        2212          0  0.388971E-01  0.136876E+00  -.344505E+01  0.356920E+01  0.922247E+00  0.391988E+00  -.250041E+01  0.492227E+00  0.354896E+00
       417        2112          0  0.108652E+00  -.237422E+00  0.158597E+01  0.186100E+01  0.938000E+00  0.591308E+00  -.141934E+01  0.492227E+00  0.354896E+00
       418        3214          0  -.369626E+00  0.538611E+00  -.902413E+00  0.177666E+01  0.138400E+01  0.391988E+00  -.250041E+01  0.492227E+00  0.354896E+00
       419         323          0  -.385163E+00  0.494673E-02  -.520771E+00  0.110659E+01  0.897202E+00  0.391988E+00  -.250041E+01  0.492227E+00  0.354896E+00
       420        -211          0  0.169742E+00  0.142902E-01  0.176272E-01  0.219934E+00  0.138000E+00  0.391988E+00  -.250041E+01  0.492227E+00  0.354896E+00
       421         215          0  0.421414E+00  -.239381E+00  -.759352E+00  0.162001E+01  0.134644E+01  0.391988E+00  -.250041E+01  0.492227E+00  0.354896E+00
      ...
      1        2       20     7195  200.000   0.1034E+01   0.0000E+00   0.0000E+00   0.0000E+00
      9203         333          0  0.628558E+00  0.154830E+01  -.718950E+00  0.209226E+01  0.103360E+01  0.583285E+02  0.147331E+03  -.666673E+02  0.200000E+03
     10810         311          0  0.471047E+00  0.831808E+00  -.464134E+00  0.117186E+01  0.494000E+00  0.583285E+02  0.147331E+03  -.666673E+02  0.200000E+03
     10811        -311          0  0.157511E+00  0.716491E+00  -.254817E+00  0.920401E+00  0.494000E+00  0.583285E+02  0.147331E+03  -.666673E+02  0.200000E+03
   1506        0
      9312        2212          0  -.217443E+00  -.282702E+00  0.681792E-01  0.100583E+01  0.938000E+00  -.342412E+01  0.925832E+00  0.767936E+00  0.148585E+02
     10126        2212          0  -.654243E-01  -.550743E-02  0.355518E+00  0.100526E+01  0.938000E+00  0.295572E+00  -.487734E+01  0.766687E+01  0.203332E+02
    ...
     10809        -211          0  0.602445E-01  -.219256E+00  0.389862E-01  0.268824E+00  0.138000E+00  0.124609E+03  -.109455E+03  -.194534E+02  0.200000E+03
     10811        -311          0  0.157511E+00  0.716491E+00  -.254817E+00  0.920401E+00  0.494000E+00  0.583285E+02  0.147331E+03  -.666673E+02  0.200000E+03
      0        0
```

column# OSC97	column# OSC99	format	**contents**
1	1	`(i10,2x)`	particle counter (different meaning in OSC97/99, see text)
2	2	`(i10,2x)`	HEP particle ID (see text)
	3	`(i10,2x)`	particle state (always "0" in **UrQMD**)
3	4	`(e12.6,2x)`	p_x: particle momentum
4	5	`(e12.6,2x)`	p_y
5	6	`(e12.6,2x)`	p_z
6	7	`(e12.6,2x)`	E
7	8	`(e12.6,2x)`	m: particle mass
8	9	`(e12.6,2x)`	r_x^{fr}: Freeze-out position
9	10	`(e12.6,2x)`	r_y^{fr}
10	11	`(e12.6,2x)`	r_z^{fr}
11	12	`(e12.6,2x)`	t^{fr}

Table 14: Formats and contents of the OSCAR particle vectors.

OSC1997A-output, but there are notable differences. All header files are preceeded by a hash sign "#".

1. Specifies output format (i.e., "`# OSC1999A`")
2. File contents, (i.e., "`# full_event_history`")
3. name and version of the model, e.g. "`# UrQMD 3.4`"
4. General information, see Table 12

The remaining file after the comments contains the full history of each event in blocks of data, very similar to the output in `15`. Each block describes one interaction with a block header and a particle list, whose length is determined by the first to columns (N_{in} and N_{out}) of the block header.

In **UrQMD**'s OSCAR output, the remaining fields in the block header vary depending on context. For the **initial particle list** ($N_{\mathrm{in}} = 0$, see line 5 in Listing 9), the fields are

3. event counter (format `(i7,2x)`)
4. impact parameter (format `(f8.3,2x)`)
5. "0" (format `(f8.3,2x)`)

For the final particle list ($N_{\mathrm{out}} = 0$, see line 33431 in Listing 9), no additional output is written. Scattering entries ($N_{\mathrm{in}} \cdot N_{\mathrm{out}} \neq 0$, see lines 422 and 33427 in Listing 9) contain information identical to that in the collision header of `15`, see Table 10.

The following $N_{\mathrm{in}} + N_{\mathrm{out}}$ lines show first the incoming and then the outgoing particles. The format is similar to the particle vector of OSCAR 1997A output, see Table 14.

In contrast to OSCAR 1997A output, the first field of the particle vector is a unique particle identifier which is created for a particle at its production point and is retired for the duration of the event at the destruction/scattering vertex of the respective particle. It thus can be used to track trajectories of particles in the course of the reaction.

Listing 9 shows a sample output in the OSC1999A format.

6.6.3 OSCAR 2008H format: fort.f21

OSCAR2008H is a standardized hydro output format. In **UrQMD** the file consists of 16 lines header followed by either the hypersurface or the hydro-evolution output, depending on the value of `CTOption(54)`. After this, the event body starts. Its contents are documented in Table 15. A sample output of each can be found in Listings 10 and 11. Here is the description of the header contents.

line 1 Consists of three strings specifying the file format, namely 'OSCAR2008H', 'ideal' for ideal hydrodynamic evolution, and 'history' or 'final_hs' for output of the whole hydro evolution or only the final hyper surface.

line 2-4 Start with 'INIT: ' and contain information about the properties of the colliding system, namely, projectile and target nucleus, impact energy, impact parameter, ground state baryon density, ground state energy density, hydro start-time, particlization scenario and value of the particlization criterion.

line 5 Starts with 'EOS: ' and specifies the used equation of state.

line 6 Starts with 'CHARGES: ' and specifies the conserved currents in the hydro evolution. 'baryon' in the **UrQMD** case.

line 7 Starts with 'HYPER: ', followed by a description of the particlization criterion.

line 8 Starts with 'GEOM: ' and specifies the geometry assumed in the calculation. '3d-cart' in the **UrQMD** case, meaning full 3d with Cartesian coordinates.

line 9 Starts with 'GRID: ' and specifies whether the calculation has been performed on an Eulerian or a Lagrangian grid.

line 10 Contains seven numbers specifying (in this order), the maximum number of timesteps, the number of cells in all three directions, the number of conserved charges, the number of dissipative components printed for a viscous hydro calculation (0 in **UrQMD**), and the number of transport coefficients printed (0 in **UrQMD**).

line 11 Contains eight numbers that specify the position of the hydro grid in space-time. They are grouped in four sets containing the lower and upper edges of the grid in time, x, y and z direction.

line 12 Is 'VISCOSITY: none' in **UrQMD**, stating that no viscosity is included in the calculation.

column#		
hypersurface	full evolution	contents
1-4	1-4	particle position cell index in (t,x,y,z in this order)
5	5	local restframe energy density in GeV
6	6	pressure in GeV
7	7	temperature in GeV
8	8	fraction of QPG liquid in cell
9-10	9-10	fluid velocity (x,y in this order)
	11	longitudinal fluid rapidity
11		fluid velocity in z
12	12	baryon density
13	13	chemical potential in GeV
14		strangeness chemical potential in GeV
15-18		hypersurface vector (t,x,y,z in this order)

Table 15: OSCAR2008H hypersurface output body elements.

line 13-15 Comment lines starting with 'COMM'.

line 16 Consists of 'END_OF_HEADER' and ends the header.

Listing 10: Excerpt from hyper surface OSC2008H output. **Please Note:** Floating point values have been abbreviated.

```
OSCAR2008H ideal final_hs
INIT: UrQMD, 10 5 on 10 5 at E_CM= 6.41 AGEV
INIT: b= 0.0000 n_B,0= 0.1589 e_0= 0.1465
INIT: start time 1.2355 grad FO crit. 0.7326
EOS: Lattice Eos from chiral model
CHARGES: baryon
HYPER: grad FO crit. 0.7326
GEOM: 3d-cart
GRID: Euler
  1000 200 200 200 1 0 0
    1.236 81.236 -20.100 19.900 -20.100 19.900 -20.100 19.900
VISCOSITY: none
COMM: SHASTA by D. Rischke
COMM: modified by H. Petersen & M. Bleicher
COMM: axis order, z-y-x
END_OF_HEADER
    0.8800 1.3000 -6.5000 -1.3000 0.0000 0.0000 0.0000 0.0000 0.1436E+00 -0.6465E+00 -0.7491E+00 0.0000 0.0000 0.0000 0.0080 0.0000
0.0000 0.0000
    0.8800 1.5000 -6.5000 -1.3000 0.0000 0.0000 0.0000 0.0000 0.1439E+00 -0.6478E+00 -0.7478E+00 0.0000 0.0000 0.0000 0.0080 0.0000
0.0000 0.0000
    ...
```


Listing 11: Excerpt from full evolution OSC2008H output **Please Note:** Floating point values have been abbreviated.

```
OSCAR2008H ideal history
INIT: UrQMD, 208 82 on 208 82 at E_CM= 17.43 AGEV
INIT: b= 0.0000 n_B,0= 0.1589 e_0= 0.1465
INIT: start time 1.4149 grad FO crit. 0.7326
EOS: Lattice Eos from chiral model
CHARGES: baryon
HYPER: full evolution
GEOM: 3d-cart
GRID: Euler
  1000 200 200 200 1 0 0
    1.415 81.415 -20.100 19.900 -20.100 19.900 -20.100 19.900
VISCOSITY: none
COMM: SHASTA by D. Rischke
COMM: modified by H. Petersen & M. Bleicher
COMM: axis order, z-y-x
END_OF_HEADER
    9 1 1 1 0.0000 0.0000 0.0000 0.0000 0.0000E+00 0.0000E+00 0.0000E+00 0.0000 0.0000
    9 1 1 2 0.0000 0.0000 0.0000 0.0000 0.0000E+00 0.0000E+00 0.0000E+00 0.0000 0.0000
    ...
```

6.7 Reading old events

With file 10 specified, **UrQMD** tries to read an old event file from 10. CTOption(40) controls the behaviour:

- If CTOption(40)=0, a warning is issued and CTOption(40) is set to 2. (Note that, of course, this only applies when an old event is read.)
- If CTOption(40)=1, all CTOption() and CTParameter() are set to the values specified in 10.
- If CTOption(40)=2, only those CTOption() and CTParameter() that are marked with an asterisk in 10 are set to the value from that file, all others are set as usual (default values or values from 9).

Please Note: CTOption(40) and CTOption(41) are never set from the old event file, since they are specific to the continuation of the event. Thus, output from a continued event can also be in "normal" standard output file-format if that is specified in the input file 9.

Please Note: while there is a check to see if the input 10 was written with CTOption(41) turned on, only a warning is issued in case it wasn't. Probably, **UrQMD** will exit ungracefully.

Please Note: when using CTOption(40) > 0 for self-generated files, make sure that all the baryons are listed first followed by all the mesons. This particle order is necessary to avoid further complications. We recommend you use CTOption(40)=2 to run UrQMD with standard values where you don't explicitly want something else.

7 Appendix A: Change logs

This section contains the change logs for **UrQMD**. The use of old versions of **UrQMD** is highly not recommended. Please use only the newest version of **UrQMD**.

The change logs are **not** meant to be annotated diffs. Thus, they list changes relevant for the end user, i.e., which bugs have been fixed, which new options and parameters have been added and what new physics assumptions have been introduced. Also, we try to give a hint about how the results have changed.

See also file ChangeLog included in **UrQMD** releases for a more "annotated diff"-like Change log.

7.1 Version 1.2

New OSCAR output

The OSC1999A OSCAR intermediate file output format has been added.

This format is similar to our collision-file output format, but adheres to the new OSCAR OSC1999A output convention. Output is written to 20.

New features include particle ID according to the PDG Monte-Carlo ID scheme [9] and a new global quantum number, uid (stands for Unique Particle ID), i.e. a serial number the particle gets at

creation and which is retired from the event after the particle undergoes an interaction. This ID is supposed to make the tracing of a particle through the collision file easier, since it does not change dynamically as our particle-slots/numbers do, due to the internal **UrQMD** memory management.

Bug-fixes and improvements

- In GNUmakefile there is a small modification for the code to run on Alpha-machines.
- Complete rewrite of gnuranf.f, which is now the default for Linux.
- A new angular distribution in the meson-baryon channel is used. I.e. isotropic resonance decays below an invariant mass of 6 GeV and a forward-backward behavior above. angdis.f: for collisions with $\sqrt{s}$ larger than 6 GeV zero degree scattering is enforced (only deflection from string decay).
- A sign-error in angdis.f has been corrected. This error led to a wrong symmetry in meson-baryon collisions (only visible when running **UrQMD** for elementary hadron-hadron collisions).
- New environment variable URQMD_TAB to find tables.dat.
- Higher meltpoint for resonant meson absorption on baryons (only η, ρ, ω and all hyperon channels).
- Bugfix in meson-meson annihilation cross section.
- string.f: subroutine ityp2id case of u-quark anti-u quark: quark ids corrected from 2 and -2 to 1 and -1.
- make22.f: sighera warning only active if new logical variable warn is true. Analogously defined as variables check and info in coms.f. As default the variable warn is set to false to avoid countless warnings.
- In coms.f, nmax = maximum number of particles is increased from 5,000 to 40,000. Therefore, in input.f, a warning is issued if calculations are performed for energies $E_{\rm lab}$ or $p_{\rm lab} < 200$ AGeV or $\sqrt{s_{\rm NN}} < 20$ AGeV.
- colltab.f: ncollmax: maximum number of entries in collision tabl is increased from 5,000 to 10,000.

7.2 Version 1.3

Initialization

A new initialization method for cascade mode has been implemented. The initialization method used in **UrQMD** 1.0-1.2 led to an increased nucleon density on the surface of the nucleus and a too small total collision cross-section. For calculations with Skryme equation of state (eos$\neq$ 1), the old initialization method is still the recommended one.

> **Caution!** Due to the new initialization method calculations made with **UrQMD** version 1.3 or later may give results deviating from the results published with earlier versions of **UrQMD**!

To reproduce old results you can set `CTOption(24)`=0 to get the old initialization.

New Options

- New parameter `CTParameter(21)` allows the initialization of deformed nuclei. The parameter gives the deformation parameter (default is 0.0).
- New option *stb* prevents the decay of a particle type. Multiple definitions of *stb* in the input file are allowed.
- Phase space correction for upper mass limit of resonances. This feature is important for correct dilepton spectra. To enable this feature set `CTOption(25)`=1. Default is 0.
- Alternate parametrisation of the $p\bar{p}$ annihilation crosssection with `CTOption(38)`. For a detailed description of the two parametrizations see [10]
- New option `CTOption(41)`=2: elastic collisions no longer overwrite the production process. Instead, elastic collisions increment the 3$^{\text{rd}}$ digit of origin (origin+=100). A process with Process ID 27 and no color exchange is treated as an elastic collision.

New Channels

To improve the description of Kaon production at low energies the following channels have been implemented:

$$p + p \rightarrow p + \Sigma^+ + K^0 \tag{1a}$$
$$p + p \rightarrow p + \Sigma^0 + K^+ \tag{1b}$$

$$p + p \rightarrow p + p + f_0 \rightarrow p + p + K^+ + K^- \tag{1c}$$
$$p + p \rightarrow p + p + a_0 \rightarrow p + p + \bar{K}^0 + \bar{K}^- \tag{1d}$$
$$\pi^- + p \rightarrow N^* \rightarrow n + f_0 \rightarrow n + K^+ + K^- \tag{1e}$$

7.3 Version 2.3

UrQMD versions 2.0 – 2.2 are considered unstable development versions. Version 2.3 has been tested in detail. Particle spectra obtained with this version can be found in [14].

Inclusion of Pythia

PYTHIA 6.409 is included for hard scatterings for $\sqrt{s}_{\text{min}} \leq 10$ GeV. Hard collisions are presently defined as collisions with momentum transfer $Q > 1.5$ GeV. The transition between the low energy string routine and Pythia is smooth and given by the probability distribution for hard scatterings. PYTHIA can be disabled by setting `CTOption(44)`=0.

Adjustments of the interface PYTHIA/UrQMD

- Particles unknown to **UrQMD** obtain a shift in ityp by ± 1000 (sign depends on the sign of the ityp). **Please Note:** exotic PDG particle codes can now be encountered in the **UrQMD** and OSCAR output!
- Particles unknown to **UrQMD** are considered stable and they are assigned a strangeness and a spin of zero. The charge is correctly calculated.
- Unknown particles from PYTHIA do not interact.

Inclusion of high mass resonances

High mass resonances are included in the energy regime between $\sqrt{s}_{\mathrm{coll}} = 1.67$ GeV and $\sqrt{s}_{\mathrm{coll}} =$ `CTOption(60)` GeV. The formed particle excitations are treated as pseudo-resonances instead of strings. Below $\sqrt{s}_{\mathrm{coll}} = 1.67$ GeV, normal resonance excitation takes place. Above $\sqrt{s}_{\mathrm{coll}} =$ `CTOption(60)` GeV the normal **UrQMD**string-routine is called. Parameters for the unknown resonances are extrapolated from the nearest available resonance.

To fix the strangeness production cross section which was reduced because of the new production of high mass resonances instead of strings the branching ratios of high lying resonances are changed to the corresponding branching ratios obtained from string decays of the same mass. Further adjustments are made to keep the particle properties in line with the Particle Data Book 2006.

Other new features

- New Regge-parametrisations for cross-sections at high energies are implemented.
- Fix the mass distribution of the nucleon resonances N^* via inclusion of the Delta resonances.
- Adjust Ξ- and Ω-production rates in pp-collisions to newly available data via the value of `CTParameter(29)`.

Bug fixes

- New channel (Process-ID 39) for baryon-antibaryon interactions to allow for string production at high energies.
- An out-of-bounds error occuring in `coload.f` is eliminated.
- `dwidth.f` nrejmax: 5,000 $\rightarrow$ 1,000,000 to avoid warning. Can be changed back if speed is more important than the details of the mass distribution.
- Bug in $p\bar{p}$-cross-section has been fixed. Now pp and $\bar{p}p$ cross sections and scattering processes become similar at high energies.
- The Pauli-blocking is reset to old value after final decay for next event.
- Charge conservation check before and after the call of **&**scatter**(**).

New formats, options and parameters

- The **UrQMD** logo (with PYTHIA credentials) is shown at startup.

- Output formats have been changed to make ityp and lstcoll fields long enough for new PYTHIA particles.
- Time format in standard event header has been changed.
- Single strange diquark suppression via `CTParameter(49)` is set to 0.5.
- Default value of `CTParameter(29)` = 1: No additional strange diquark suppression.
- New parameter `CTParameter(59)` = 0.4: scaling factor for leading hadron cross section for Pythia particles.
- New parameter `CTParameter(60)` = 3: resonance/string transition energy for high mass resonances.
- New option `CTOption(44)` = 1: call Pythia for hard scatterings
- New option `CTOption(46)` = 0: Density calculation switch (default is baryon density)
- Faster initialization of nuclei with `CTOption(24)` =2 (needed for cosmic ray calculation)

7.4 Version 2.3-p1

Fixes a minor bug in the angular distribution of particles that are produced in string fragmentation (not via PYTHIA). Bug was introduced in u2.3. It has led to outgoing particles which have zero momentum in x- and y-direction in elementary p-p collisions. The multiplicities and particle spectra are unchanged by this bugfix. Thanks to Katarzyna Grebieszkow for pointing us to the problem.

7.5 Version 3.3

Charm rescattering

Implementation of charmed hadrons with the following itypes: D (133), D* (134), J/Ψ (135), Ψ' (136), χ_c (137)

Rescattering cross sections with pions and rhos included as well, both elastic and inelastic: $D + \pi \leftrightarrow D^*$, $\rho + J/\Psi \leftrightarrow D + \bar{D}$ and $\rho + J/\Psi \leftrightarrow D^* + \bar{D}^*$

Cross sections have been parameterized from work done by Zi-Wei Lin [11, 13].

UrQMD + Hydro

It is possible to run **UrQMD** with a fluid-dynamical evolution for the hot and dense stage of the heavy ion reaction. Default calculations are still the cascade mode calculations. The fluid-dynamical evolution is calculated via the SHASTA algorithm.

- Output to scattering history file `15` has been altered: nin is set to 9 and one header line and nine particle lines at the beginning and in the end of the fluid-dynamical evolution is printed consisting only of zeroes except of the time information. In addition, a list of all particles going into and out of the fluid phase is written. **Please Note:** the format for the header lines has changed. Please refer to Section 6.4 for details.
- New Option `CTOption(45)` =1: fluid mode (default is cascade calculation)

- New Option `CTOption(47)`=2/3/5: Chose Equation of State for fluid (hadron gas EoS/Bag Model EoS/chiral+hadron gas Eos)
- New Option `CTOption(48)`=N: Calculate fluid evolution only N timesteps of fluid evolution (debugging purposes)
- New Option `CTOption(49)`: spectator switch: 0 (default): spectators are propagated seperately; 1: spectators are also put on the fluid grid
- New Option `CTOption(50)`: 1: (additional) f14/f19-output directly after fluid evolution; time is equal to $t_{\mathrm{hydrostart}}$ (for technical reasons), resonances decay immediately.
- New Option `CTOption(52)` : particlization switch: 0 (default): isochronous transverse slices; 1: completely isochronous particlization of the whole system
- New Option `CTOption(53)`: use improved momentum generation, default is zero and any other number leads to old prescription with in any case high enough maxima
- New Parameter `CTParameter(61)` = 0.2 fm : cell size for the fluid code
- New Parameter `CTParameter(62)` = 200 : number of fluid cells per dimension
- New Parameter `CTParameter(63)` = 1. fm : minimal statring time for fluid $t^{\mathrm{min}}_{\mathrm{hydrostart}}$
- New Parameter `CTParameter(64)` = 5 factor for the particlization criterium ($x * \epsilon_0$)
- New Parameter `CTParameter(65)` = 1 multiplied with $t_{\mathrm{hydrostart}}$
- New Parameter `CTParameter(66)`=1.d10 the rapidity cut for the matter that is put on the fluid-dynamical grid, necessary for calculations at higher energies than $E_{\mathrm{lab}} = 160$ AGeV.

Known problems:

- Output in timesteps according to tim statement in inputfile is not consistently possible during the fluid-dynamical evolution
- The option for test cases `CTOption(48)` does not work when using the bag model equation of state.

Bug Fixes

- `GNUmakefile` has been rewritten for use of gfortran as standard compiler in Linux. Observe that the name of the executable has been changed; please refer to the beginning of this guide for an example file how to run the code.
- Branching ratios have been improved for cases with small cross sections.
- Handling of `CTOption(7)` now works stable.
- Branching ratios for hyperon resonances are adjusted in order to ensure that they sum up to one (thanks to Pasi Huovinen).
- `CTParameter(67)` allows for test particle calculations (default is one testparticle per real particle). If this parameter is used with a value different from one, the variable ncollmax in `colltab.f` has to increased (by `CTParameter(67)`/2) and AAmax should be set to 300·`CTParameter(67)` in `inputs.f`. After that the code has to be recompiled and the file `tables.dat` has to be removed and newly generated. The output does not account for the testparticles and has to be scaled accordingly. Furthermore, the computig time increases when using this parameter.

- The freeze-out coordinates (relevant for output o13) in position space are changed to take into account the formation times of particles produced in string fragmentation processes. Only formed hadrons are able to decouple from the system.

7.6 Version u3.3p1

Bugfix in output: the association from HEP particle ID to ityp was faulty for some charmed mesons.

7.7 Version u3.4

New Features

- A new, more realistic, iso-energy density particlization hypersurface has been introduced [15]. It can be activated by setting `CTOption(52)`=2, which is also the new default setting. `CTParameter(71)` dictates the interval of timesteps at which the hypersurface is constructed. A new sampling was needed to guarantee isospin symmetry at particlization for this hypersurface.
- `CTOption(54)` enables OSCAR2008H output during the hydro evolution
- `CTOption(55)` adjusts o19 output for visualization purposes, particlization coordinates are the production points again and spatial information is added (no longer standard OSCAR output!)
- `CTOption(56)` enables Unique Particle IDs in the Collision history output o15, corresponding to the values present in OSCAR 1999A output o20.
- `CTParameter(68)` sets the width of the Gaussian in fm in the smearing at fluidization
- `CTParameter(69)`, `CTParameter(70)`: A core-corona like separation mechanism can now be used for the initial state of the fluid evolution, i.e. only the dense part of the system is propagated with fluid dynamics. The minimal constituent quark+anti-quark density for transformation to the fluid is set by `CTParameter(69)`. Only particles with pseudorapidity difference less than `CTParameter(70)` are used for the density calculation. The default for both values is chosen so that all particles are transferred by default. See [12] for more information.
- The tables for the Hadron-Gas and Chiral+Deconfinement EoS have been extended to accommodate for energy densities up to 400 times nuclear ground state energy density (roughly 50 GeV/fm^3). This is needed for LHC calculations.
- Further implementation of charm rescattering. The following charmed particles are included: D (133), D^* (134), J/Ψ (135), χ_c (136), Ψ' (137), D_s (138) and D_s^* (139). Additionally to elastic scattering, the following processes are included: $\pi + D \leftrightarrow \rho + D^*$, $\pi + D^* \leftrightarrow \rho + D$, $(\pi, \rho, K) + (J/\Psi, \chi_c, \Psi') \leftrightarrow (D, D^*, D_s, D_s^*) + (\bar{D}, \bar{D}^*, \bar{D}_s, \bar{D}_s^*)$, $(J/\Psi, \chi_c, \Psi') + Baryon \rightarrow Baryon$. Cross-sections have been parametrized to fit results from [11, 13, 16, 17, 18]. Where no elastic cross-section was found, a constant 5 mb elastic cross-section is assumed.
- **UrQMD** checks for many cases of physical, as well as numerical consistency during runtime. Should an inconsistency arise for any reason the code halts. In this case, **UrQMD** now returns

"137" instead of "0" which is the default return value if no error occurred. This is useful to check automatically for aborted **UrQMD** runs.

- **UrQMD** can now be compiled for usage at LHC energies by entering 'make LHC'. This results in larger output files.
- Setting of `CTOption()` and `CTParameter()` from old events is changed so that only options and parameters that are marked with "*" are changed. The old behaviour can be obtained with `CTOption(40)`=1 (instead of `CTOption(40)`=2). Please refer to Section 6.7.
- Standard Event Header has been extended to report all `CTOption()` and `CTParameter()` that are set. For legacy analysis code, the old behaviour can be activated with `CTOption(57)`. Please see Section 6.1.
- Standard Event Header can be written into collision history file `15` with `CTOption(58)` = 1.
- Continuing box calculations with `CTOption(40)` is now possible.
- Strangeness exchange at low relative momentum is now included into **UrQMD**. The cross-sections for $K + N \leftrightarrow \pi + \Lambda/\Sigma$, $K + \Lambda/\Sigma \leftrightarrow \pi + \Xi$ and $K + \Xi \leftrightarrow \pi + \Omega$ are taken from [19]. All reactions not included there are calculated via detailed balance, scaled via the additive quark model and/or assumed to be isospin symmetric. For the $\Lambda/\Sigma + \Lambda/\Sigma \leftrightarrow N + \Xi$ process the cross-sections are the ones from [20]. The cross-sections of the subprocesses were relayed to us in private communications with the authors.

Bug Fixes

- In particlization, Bose-Einstein statistics instead of Boltzmann statistics is used for K (ityp=$\pm$106) and K^*_{893} (ityp=$\pm$108).
- A problem regarding isospin symmetry between meson-baryon and meson-antibaryon scattering as well as a false scaling factor for meson-antibaryon scattering has been fixed:
  1. previously, reactions like $\bar{p}\pi^-$ would be calculated using the $n\pi^-$ cross-section instead of the (proper) $p\pi^+$ cross-section.
  2. all resonant $\bar{B}M$ scattering cross-sections were falsely reduced by a combinatorial factor of two which is needed for the scattering of strange mesons with strange antimesons of different type, e.g. $K\bar{K}^*$. The largest impact of this fix will be on anti-baryon spectra at the LHC.
- A wrong assignment of the next collision partner happened in rare cases. Fixing this did not result in any changes in physics.
- Charmed particle are assigned correct charges now. Previously, **UrQMD** ostensibly did not conserve electric charge in some instances. **Please Note:** this bug only affected the output. Charge in **UrQMD** is not a independent variable. All relevant quantum numbers have been, and always are, exactly conserved in **UrQMD**!
- The baryon density calculation in presence of anti-baryons is corrected. This is relevant when using the `15` output to analyze baryon densities. The densities in **UrQMD** are calculated in

the local baryon-current restframe where the velocity of the restframe $\vec{\beta}$ has been corrected:

$$\vec{\beta} = \frac{\sum_{j=1}^{N} \vec{\beta}_j \cdot P_j}{\sum_{j=1}^{N} P_j} \quad \longrightarrow \quad \vec{\beta} = \frac{\sum_{j=1}^{N} \vec{\beta}_j \cdot P_j}{\sum_{j=1}^{N} |P_j|} \ .$$

N is the number of particles, $\vec{\beta}_j$ is the β vector of particle j and P_j is the contribution of particle j to the local net-baryon density. It is positive for baryons and negative for anti-baryons.

- The current **UrQMD** version tag is now consistent in all output files. In all previous **UrQMD** versions, the string had been hard-coded to "1.2".
- New process identifiers 91 and 96 have been introduced to mark fluidization and particlization output to 15.
- In very rare cases of a pauli-blocked meson+baryon-string excitation, in which the string creates a baryon-antibaryon pair, the program threw a segmentation fault. This has been fixed.
- In $\mathrm{B\overline{B}}$ collisions with no outgoing Baryons or MM collisions with produced $\mathrm{B\overline{B}}$ pair, new particles could be created at wrong space-time points. This has been fixed.
- Negative net-baryon densities in the DE-EOS are now treated correctly.
- Algorithm to determine the masses of unstable resonances became unstable close to their minimum mass. This has been fixed.
- In very rare cases, particles that had just collided had a chance to collide again immediately. This has been fixed, reworking some of the internal bookkeeping. **Please Note:** In 13-16, the index of the last collision partner has been replaced by the unique number of the collision the particle originates from.
- All MB interactions that could not do a $\mathrm{q\overline{q}}$ annihilation accidentally had a 12.5 mbarn cross section below the sighera meltpoint. This has been fixed.
- $\Xi + \overline{\mathrm{K}} \rightarrow \Omega$ violated detailed balance, since the Ω does not decay in **UrQMD**. Now this collision is treated as a string, which results mostly in $\Xi + \overline{\mathrm{K}} \rightarrow \Xi + \overline{\mathrm{K}} + \pi$.
- The symmetry coefficients were a factor of 2 too small for $\pi^+\pi^0$,$\pi^-\pi^0$,$\rho^+\rho^0$,$\rho^-\rho^0$ channels. This has been fixed.
- Mesons coming from the last string break got zero transverse momentum. We made the changes proposed by V. Uzhinsky [21].
- The meltpoint in $\overline{\mathrm{B}} + \mathrm{M}$ has been raised from 1.7 GeV to 2.18 GeV to account for the cross section of resonances above the meltpoint, accidentally being lowered. Also the $\mathrm{n} + \pi^-$ meltpoint has been lowered to the $\mathrm{p} + \pi^+$ meltpoint.
- Fixed a bug where nucleon resonances up to 5 GeV could be produced in very rare cases. This overpopulated the p+p and peripheral p+Au $p_\perp$ spectra at $p_\perp > 2$ GeV at low collision energies.
- The scaling factor for the leading hadron cross section CTP(59) has been changed from 0.4 to 0.7 to account for new LHC data.
- Unique particle IDs are also set for initial particles in box modus. Previously, these were omitted. The bug concerned OSCAR 1999A 20 output in box mode calculations.
- E_{lab} is now written into 20 to make it OSCAR 1999A compliant.
- Resonances from hydro decayed too late by $t_{hydro,start}$ fm.
- Freeze-out coordinates in x- and z-direction were wrong up to 1 fm for particles with formation

time. Also the freeze-out time of these particles was too late.

- **UrQMD** no longer dies silently if too many particles are specified via "bpe" or "bpt" for box calculations.
- In $N + N \rightarrow N + \Delta, N + N^*, \Delta + \Delta, ...$ reactions the total and the elastic cross-section were fixed and the resonance production cross-sections were rescaled. This resulted in a violation of detailed balance and isospin symmetry. Now the total cross-section and the resonance cross-sections are fixed and the elastic cross-section is rescaled. At the same time, the start of string production in $N + N$ collisions is moved to slightly higher energies to still reproduce the measured experimental total and elastic cross-sections after this fix.
- If test-particles where used, the initial momentum distribution differed from the Fermi distribution.
- In the low energy inelastic scattering of N^* with N^* or Δ^*, a minimum mass for the produced resonance, out of the N^*, was set to be 1.6 GeV. This higher than the Δ mass. Therefore, all Δ's below this mass would become nucleons with a mass of 0.938 GeV. Now the minimum resonance mass out of the N^* is the minimum Δ mass, i.e. mass(N) + mass(π). Thus, more Δ's at lower mass will be produced.
- Fixed a bug that resulted in the $N+N \rightarrow N+N^*$ cross-section being a bit larger than originally fitted to data.

Other changes

- Removed non-critical warnings that were not useful for the user.
- The number of the collisions on the Standard Output now counts also collisions before the Hydro phase.
- Standard event header has now "pa" instead of "op" at the beginning of lines containing the CTParameter values.
- The rare cases of photon production and scattering have now been removed.

8 Appendix B: Known problems and inconsistencies in UrQMD

- More sophisticated treatment of coherent scattering will be important at very high energies.
- Detailed balance is violated due to string decays and other multi-particle (n$\geq$3) decays, e.g. $\omega \rightarrow 3\pi$, for which no inverse reactions are implemented.
- The frame dependence of the code (target vs. projectile vs. CMS-frame) leads to slightly asymmetric $\leq 5\%$ distributions and different yields in forward-backward hemispheres at RHIC.
- Output in timesteps according to tim statement in inputfile is not consistently possible during the fluid-dynamical evolution (with `CTOption(45)`)
- The option for fluid-dynamical test cases `CTOption(48)` does not work when using the bag model equation of state.

For a detailed analysis on systematic uncertainties in **UrQMD**, the reader is referred to [22].

9 Appendix C: Meson itypes

Meson itypes, sorted by ityp

ityp	Particle type
100	γ
101	π
102	η
103	ω
104	ρ
105	f_0
106	K
107	η'
108	K^*
109	ϕ

ityp	Particle type
110	K_0^*
111	a_0
112	f_0^*
113	K_1^*
114	a_1
115	f_1^*
116	f_1'
117	K_2^*
118	a_2
119	f_2

ityp	Particle type
120	f_2'
121	K_1
122	b_1
123	h_1
124	h_1'
125	K_{1410}^*
126	ρ_{1450}
127	ω_{1420}
128	ϕ_{1680}
129	K_{1680}^*

ityp	Particle type
130	ρ_{1700}
131	ω_{1662}
132	ϕ_{1900}
133	D
134	D^*
135	J/Ψ
136	χ_c
137	Ψ'
138	D_s
139	D_s^*

10 Thanks

We encourage all users to submit potential problems and bug reports to the following e-mail address: urqmd@urqmd.org .

We would like to thank everybody who has been sending suggestions, bug reports and ideas how to fix them.

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