

**Joint ICTP-IAEA Workshop on Monte Carlo Radiation Transport
and Associated Data Needs for Medical Applications**

28 October – 8 November 2024

ICTP, Trieste, Italy

Lecture 10

Phase space files

Frédéric Tessier (narrated by Hugo Bouchard)

Metrology Research Centre

National Research Council Canada

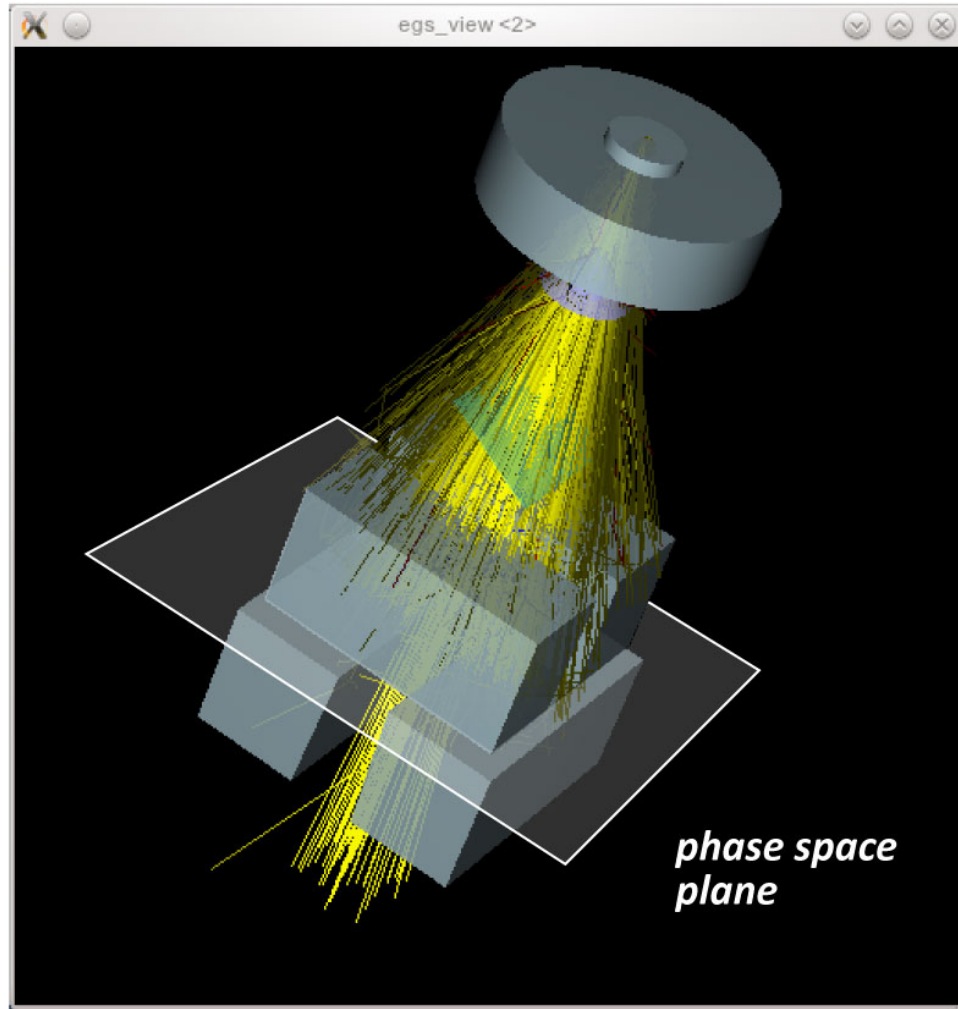


Government
of Canada

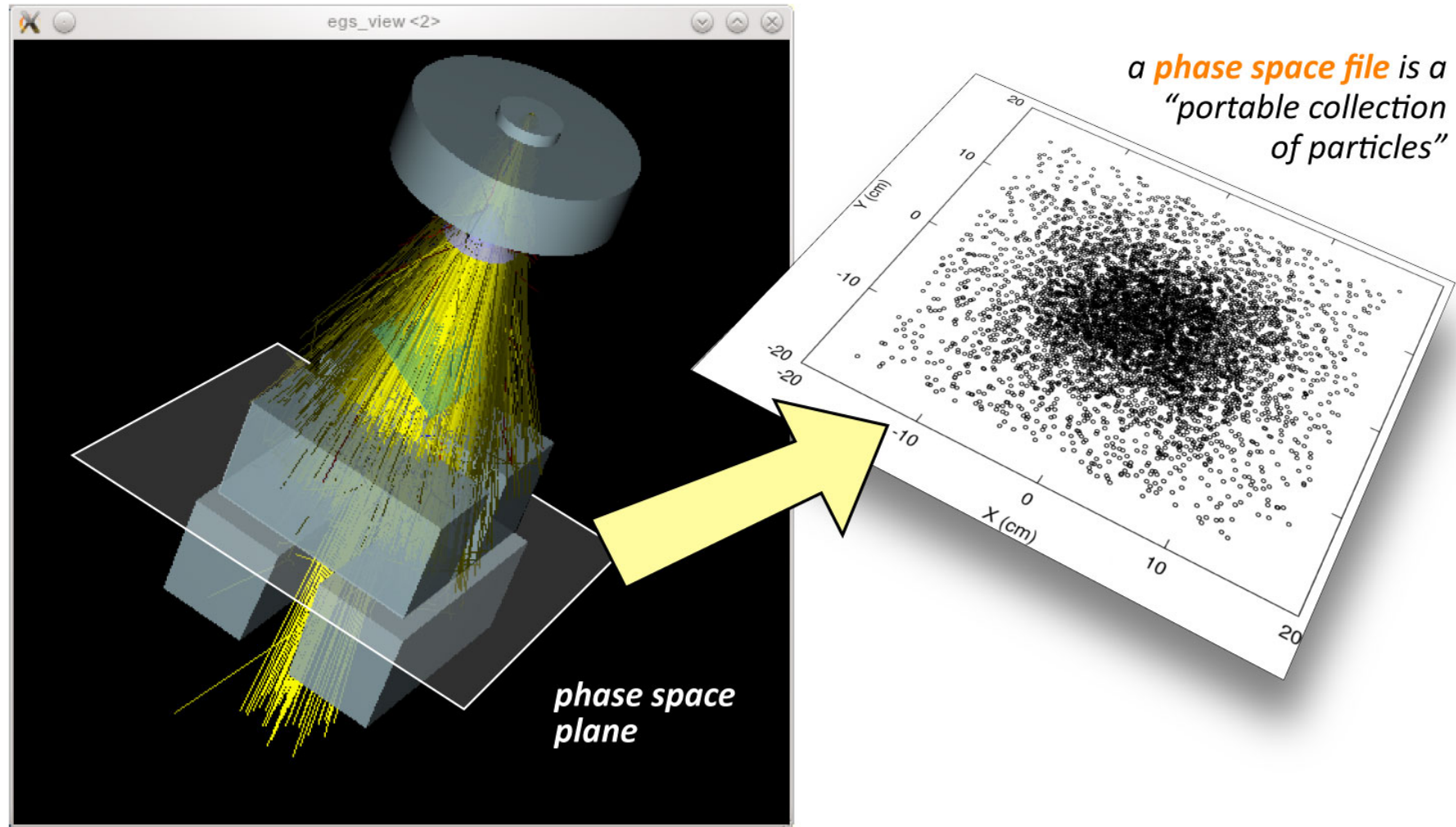
Gouvernement
du Canada



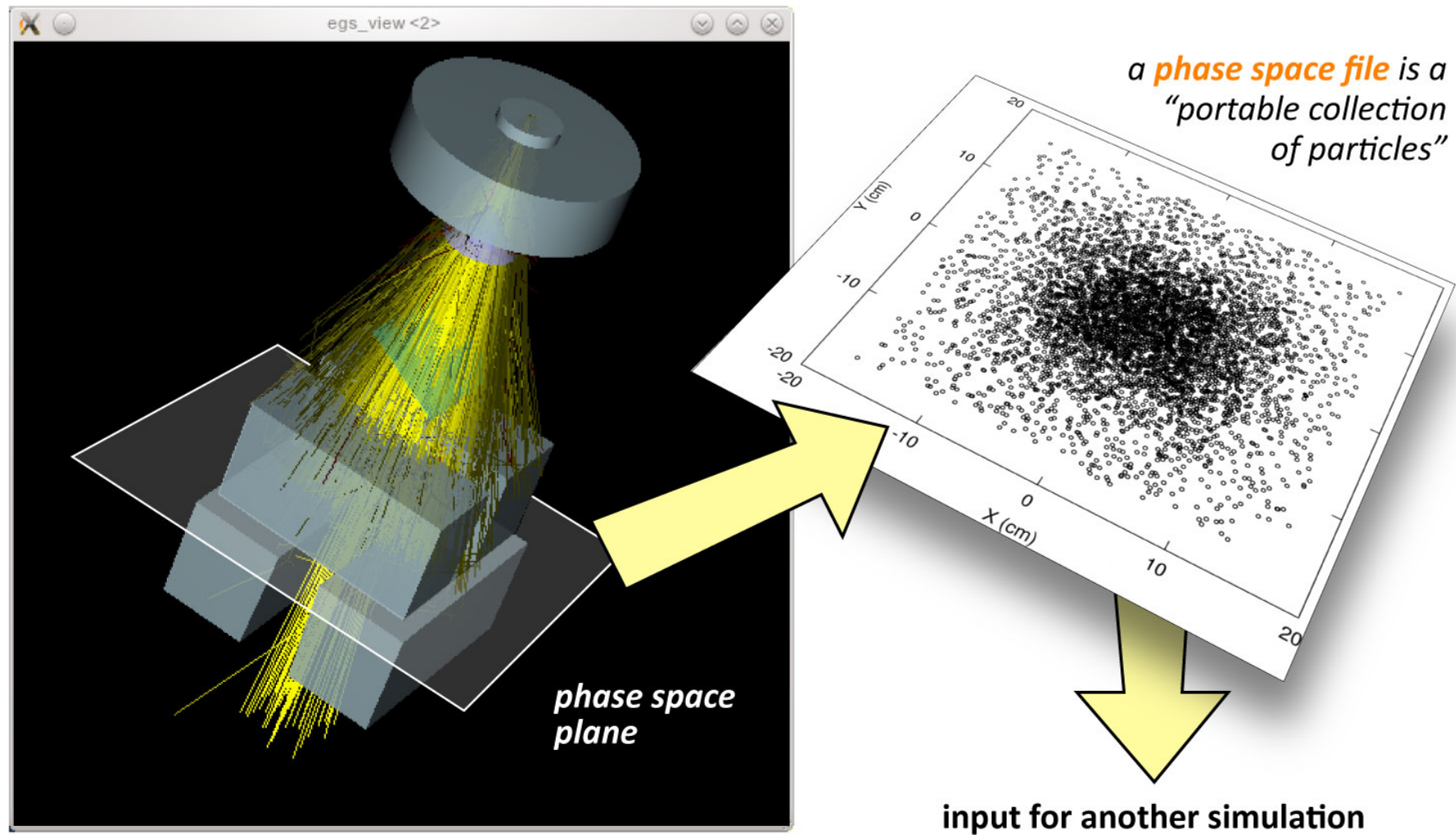
The BIG idea



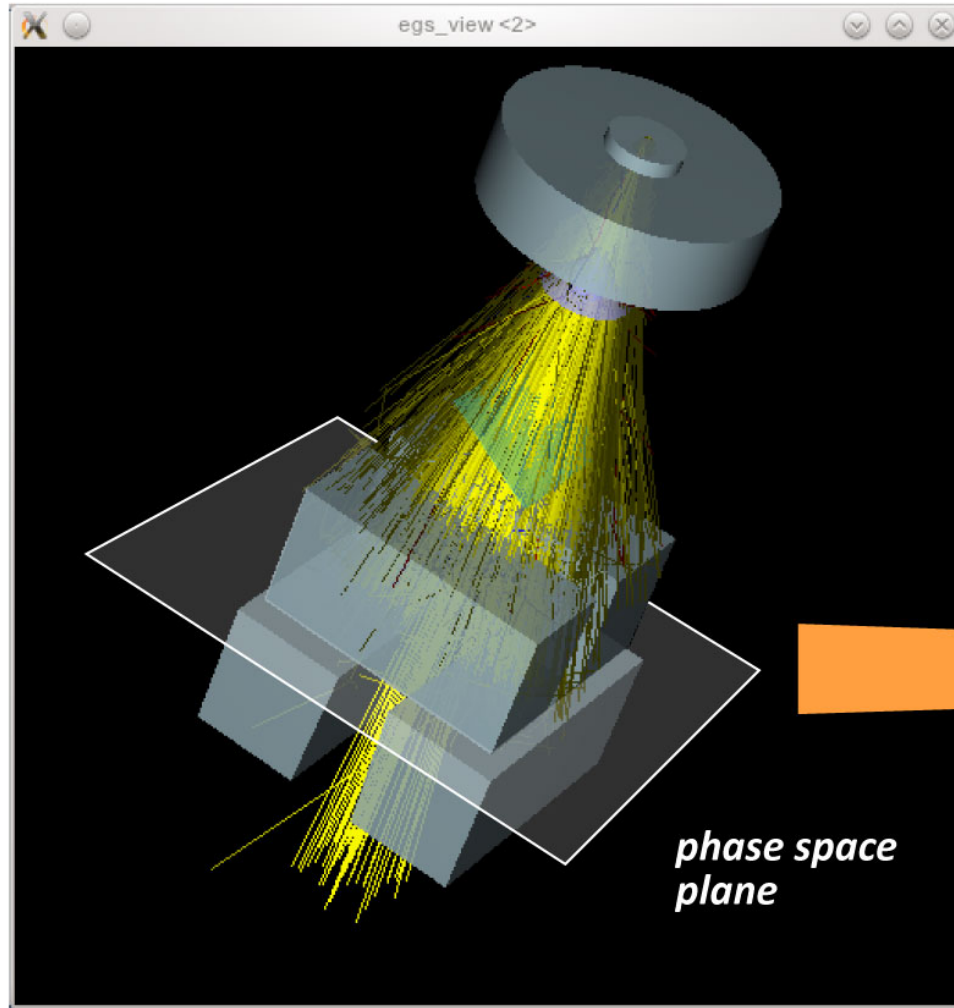
The BIG idea



The BIG idea

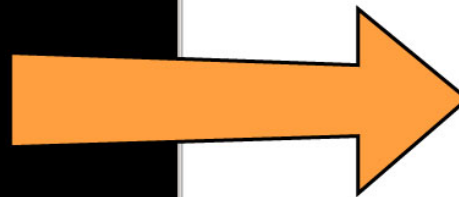


The BIGGER idea



use BEAMnrc simulation *directly*
as a source for another simulation

simulations call the BEAMnrc
shared library when they
need more particles



another simulation

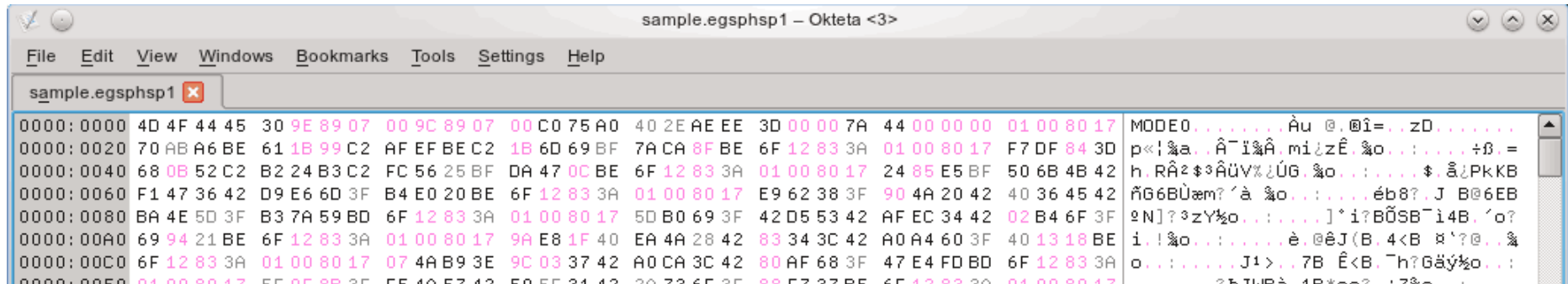
Phase space files contain particle data

Binary format :-

```
sample.egsphsp1 - Okteta <3>
File Edit View Windows Bookmarks Tools Settings Help
sample.egsphsp1 x
0000:0000 4D 4F 44 45 30 9E 89 07 00 9C 89 07 00 C0 75 A0 40 2E AE EE 3D 00 00 7A 44 00 00 00 01 00 80 17 MODE0.....Ĥu @.@i=..zD.....
0000:0020 70 AB A6 BE 61 1B 99 C2 AF EF BE C2 1B 6D 69 BF 7A CA 8F BE 6F 12 83 3A 01 00 80 17 F7 DF 84 3D p<<!%a..Ĥ-i%Ĥ.miĤzĤ %o.....+B.=
0000:0040 68 0B 52 C2 B2 24 B3 C2 FC 56 25 BF DA 47 0C BE 6F 12 83 3A 01 00 80 17 24 85 E5 BF 50 6B 4B 42 h.RÂ²$%ĤŮV%ĤŮG.%o.....$.ĤĤPkKB
0000:0060 F1 47 36 42 D9 E6 6D 3F B4 E0 20 BE 6F 12 83 3A 01 00 80 17 E9 62 38 3F 90 4A 20 42 40 36 45 42 ĤG6BÙæm? 'à %o.....éb8?.J B@6EB
0000:0080 BA 4E 5D 3F B3 7A 59 BD 6F 12 83 3A 01 00 80 17 5D B0 69 3F 42 D5 53 42 AF EC 34 42 02 B4 6F 3F ēN]?'%zY%o.....]'i?BŮSB-Ĥ4B.'o?
0000:00A0 69 94 21 BE 6F 12 83 3A 01 00 80 17 9A E8 1F 40 EA 4A 28 42 83 34 3C 42 A0 A4 60 3F 40 13 18 BE i.!!%o.....è.@ēJ(B.4<B %`?@.%%
0000:00C0 6F 12 83 3A 01 00 80 17 07 4A B9 3E 9C 03 37 42 A0 CA 3C 42 80 AF 68 3F 47 E4 FD BD 6F 12 83 3A o.....J!>..7B Ĥ<B.'h?GĤy%o...
0000:00E0 04 00 80 17 5F 0F 8B 3F 5F 40 53 42 50 5F 34 42 30 73 6F 3F 88 F7 37 BF 6F 12 83 3A 01 00 80 17
```


Phase space files contain particle data

Binary format :-



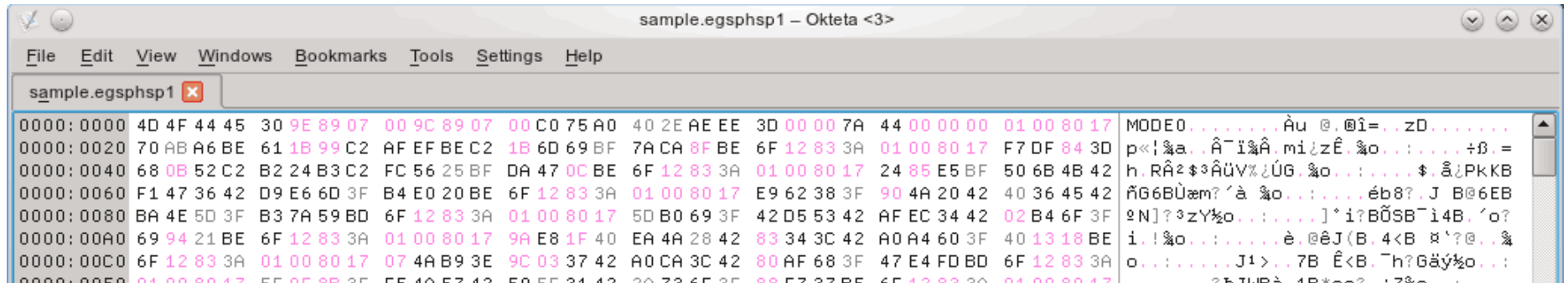
There is one phase space file for each scoring plane

inputfile.egsphsp#

where #=1,2,3,...

Phase space files contain particle data

Binary format :-)



There is one phase space file for each scoring plane

inputfile.egsphsp#

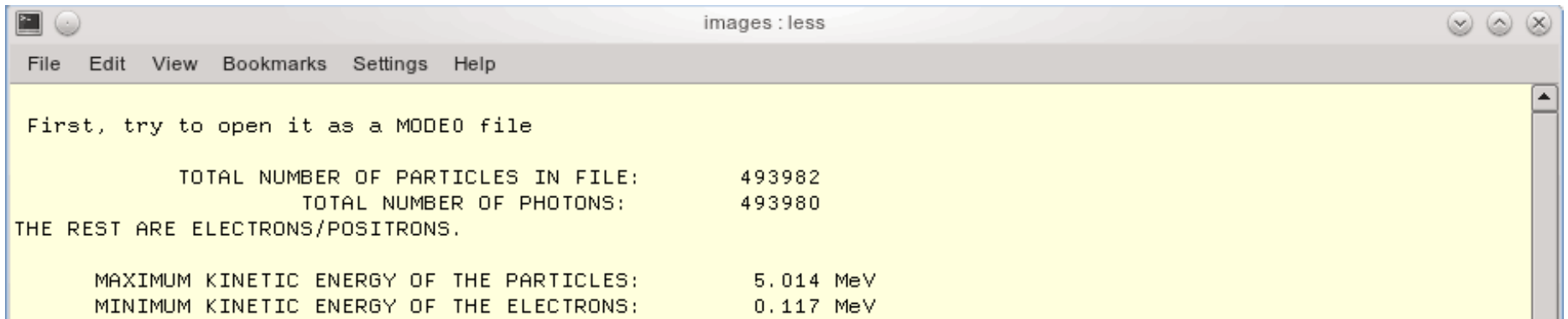
where #=1,2,3,...

Mind the file size!

Phase space files can rapidly grow to fill an entire hard drive. Test for a small number of histories in order to gauge the size of the phase space file for your final simulation.

A phase space file starts with a header

MODE_RW	MODE0 (no ZLAST) or MODE2 (with ZLAST)
NPPHSP	total number of particles in file
NPHOTPHSP	total number of photons in file
EKMAXPHSP	maximum kinetic energy of particles
EKMINPHSPE	minimum kinetic energy of electrons
NINCPHSP	number of particles incident from original source



```
images : less
File Edit View Bookmarks Settings Help

First, try to open it as a MODE0 file

      TOTAL NUMBER OF PARTICLES IN FILE:      493982
      TOTAL NUMBER OF PHOTONS:              493980
THE REST ARE ELECTRONS/POSITRONS.

      MAXIMUM KINETIC ENERGY OF THE PARTICLES:      5.014 MeV
      MINIMUM KINETIC ENERGY OF THE ELECTRONS:      0.117 MeV
```

A phase space file is a list of particles

For each particle

LATCHTMP [-]ESHORT X Y U V W WEIGHTTMP [ZLAST]

where:

LATCHTMP	LATCH value, charge (bits 29-30) and NPASS (bit 31)
ESHORT	total energy; set negative for new history
X	position along X axis (cm)
Y	position along Y axis (cm)
U	direction cosine with respect to X axis
V	direction cosine with respect to Y axis
W	direction cosine with respect to Z axis
WEIGHTTMP	statistical weight of particle, and sign of direction along the Z axis
ZLAST	photons: Z position of the last interaction; electrons: Z position where electron or its ancestor was set in motion by a photon

A phase space file is a list of particles

```
images : less
File Edit View Bookmarks Settings Help

First, try to open it as a MODE0 file

TOTAL NUMBER OF PARTICLES IN FILE:          493982
TOTAL NUMBER OF PHOTONS:                   493980
THE REST ARE ELECTRONS/POSITRONS.

MAXIMUM KINETIC ENERGY OF THE PARTICLES:    5.014 MeV
MINIMUM KINETIC ENERGY OF THE ELECTRONS:    0.117 MeV
# OF INCIDENT PARTICLES FROM ORIGINAL SOURCE: 1000.0


ENERGY  IQ      X        Y        U        V        W      WEIGHT      LATCH (set=1, not set=0)

0.326   0 -76.553 -95.468 -0.912 -0.281  0.300 1.000E-03 10111 1000000000000000000000001
0.065   0 -52.511 -89.572 -0.646 -0.137  0.751 1.000E-03 10111 1000000000000000000000001
1.793   0  50.855  45.570  0.929 -0.157  0.334 1.000E-03 10111 1000000000000000000000001
0.720   0  40.073  49.303  0.864 -0.053  0.500 1.000E-03 10111 1000000000000000000000001
0.913   0  52.958  45.231  0.936 -0.158  0.314 1.000E-03 10111 1000000000000000000000001
2.499   0  42.073  47.051  0.878 -0.149  0.456 1.000E-03 10111 1000000000000000000000001
0.362   0  45.754  47.198  0.909 -0.124  0.398 1.000E-03 10111 1000000000000000000000001
1.086   0  53.823  44.344  0.935 -0.180  0.305 1.000E-03 10111 1000000000000000000000001
3.718   0  46.349  47.150  0.913 -0.123  0.390 1.000E-03 10111 1000000000000000000000001
0.176   0  13.763  47.468 -0.668 -0.118  0.735 1.000E-03 10111 1000000000000000000000001
1.735   0  46.113  75.410  0.660  0.695  0.285 1.000E-03 10111 1000000000000000000000001
2.277   0  57.261  32.035  0.857 -0.450  0.252 1.000E-03 10111 1000000000000000000000001
1.012   0  41.756  46.688  0.872 -0.166  0.460 1.000E-03 10111 1000000000000000000000001
0.157   0  28.377  44.695  0.401 -0.450  0.798 1.000E-03 10111 1000000000000000000000001
0.636   0  43.376  46.380  0.886 -0.169  0.432 1.000E-03 10111 1000000000000000000000001
0.628   0  38.449  43.908  0.799 -0.321  0.508 1.000E-03 10111 1000000000000000000000001
0.401   0  23.484  45.936  0.011 -0.394  0.919 1.000E-03 10111 1000000000000000000000001
0.423   0  41.789  48.657  0.882 -0.079  0.465 1.000E-03 10111 1000000000000000000000001
```

Changing where phase space files are written

1. Add the following input to your `.egsinp` file (either just before or just after the other EGSnrc inputs):

```
:start user inputs:
```

```
PHSP OUTPUT DIRECTORY= /full/path/to/new/output/directory
```

```
:stop user inputs:
```

2. To change the destination for phase space files globally, edit the file `$OMEGA_HOME/beamnrc/beamnrc_user_macros` and change the macro


```
REPLACE {$DIRECTORY-FOR-PHSP} WITH {$cstring(egs_home)//$cstring(user_code)};
```

to read

```
REPLACE {$DIRECTORY-FOR-PHSP} WITH {'/full/path/to/new/output/directory'};
```

Don't forget to recompile your accelerator(s) for this change to take effect!

IAEA format for phase space files



International Atomic Energy Agency

Nuclear Data Services

Section Données Nucléaires, AIEA

Phase-space database for external beam radiotherapy

IAEA NAPC Nuclear Data Section


IAEA NAHU Dosimetry and Medical Radiation Physics Section

Project Officer: [Roberto Capote](#)


Objective: To build a database and disseminate representative [phase-space data](#) of accelerators and Co-60 units used in medical radiotherapy by compiling existing data that have been properly validated.

NEWS

WE ARE WA



How to produce and submit phase-space data: The IAEA phsp format was designed to cover both phase-space files and event generators (see [phsp_contents](#)). We have implemented the IAEA phsp format in a set of [read/write routines](#) (Updated: September 2013, see [readme file](#)). Native IAEA phsp format is available in EGSnrc and PENELOPE Monte Carlo codes. Geant4 interface to use the native IAEA phsp format is also [available](#). Once the validated phsp data is produced and documentation is published, [you may submit your phsp for review](#) using the [upload link here](#).



How to download phase-space data: You have to select a phsp data type among [Co-60 source](#), [linac electron](#) or [linac photon](#) phsps. For photon and electron PHSPs you may download the header first to decide which data you want to retrieve. Once decided you should download the PHSP data from the corresponding sub-directory. Please note that the first time access to the selected subdirectory could be slow.

International Advisory Committee (IAC)

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I. Kawrakow
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Mailing Lists

Send mail to all members of the IAC
Register to the IAEA PHSP mailing list

Medical Portal

Atomic and nuclear data for medical applications

IAEA NAPC/NDS


Nuclear Data Section

IAEA NAHU/DMRP



Tech. Report

IAEA-NDS-0484



PHSP format

List of PHSP variables

PHSP Header

How to fill header ...

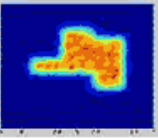
PHSP upload

Upload files

PHSP to review

Files to review

PHSP database



1. Co-60 phsps

IAEA format for phase space files

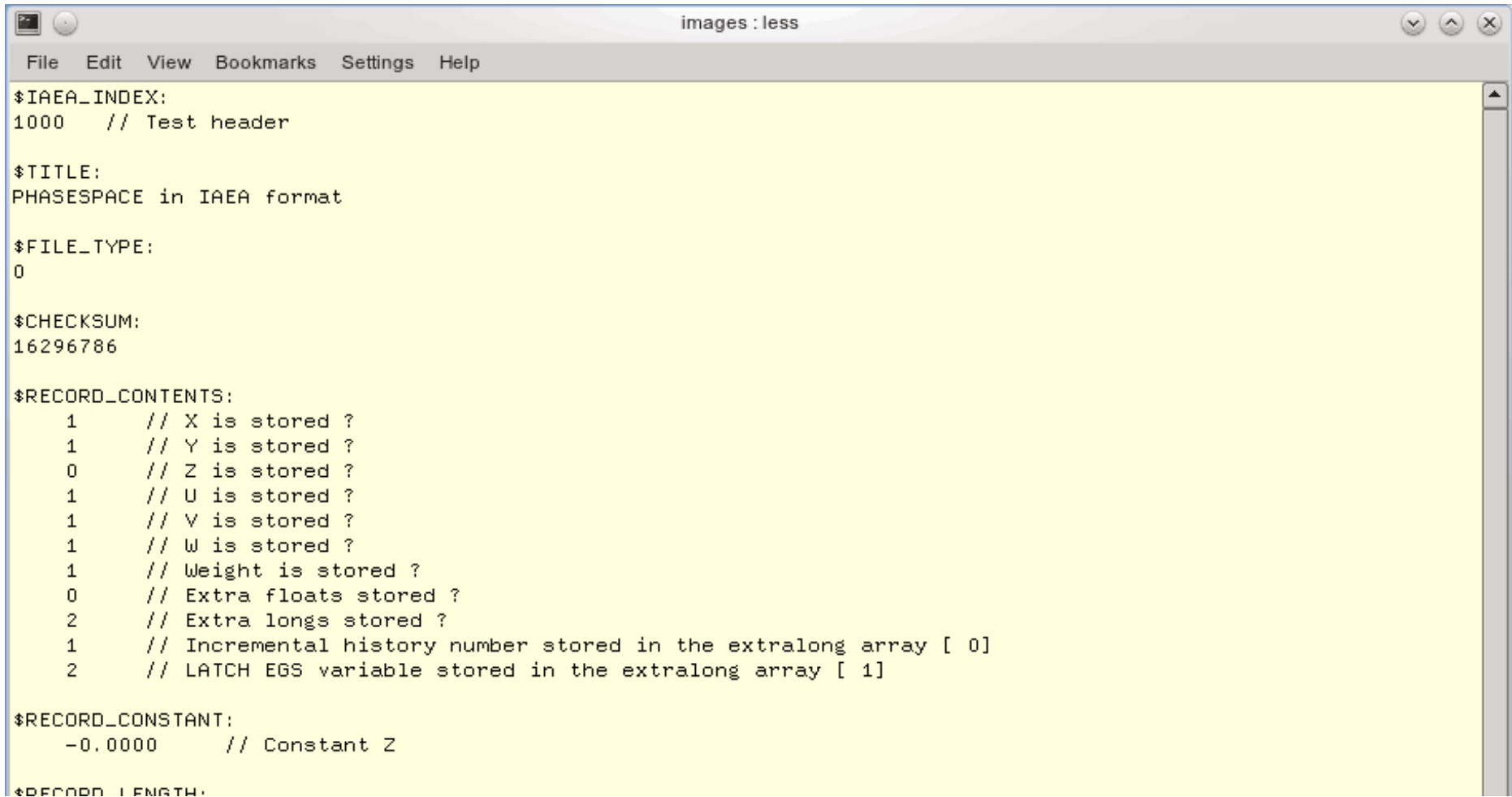
- Can make use of the International Atomic Energy Agency (IAEA) online accelerator phase space database: www-nds.iaea.org/phsp/.
- More details on this format are given by Capote et al. in IAEA report INDC (NDS)-0484.
- In order to be able to read and write in IAEA phase space format, EGSnrc and BEAMnrc must be configured on a system with a **working C++ compiler**.
- If the system is properly configured, then the IAEA phase space handling routines are automatically compiled for you in the shared object
[\\$HEN_HOUSE/egs++/dso/iaea_phsp.so](#)

The IAEA format specifies a separate header file

The **text format** `.IAEAheader` file contains:

<code>\$CHECKSUM</code>	size of phase space file.
<code>\$RECORD_CONTENTS</code>	description of data stored
<code>\$RECORD_CONSTANT</code>	values which are constant, e.g., Z of scoring plane for BEAMnrc
<code>\$RECORD_LENGTH</code>	size of each particle data record, in bytes
<code>\$BYTE_ORDER</code>	"1234" for little endian, "4321" for big endian
<code>\$ORIG_HISTORIES</code>	number of primary histories
<code>\$PARTICLES</code>	total number of particles
<code>\$PHOTONS</code>	number of photons
<code>\$STATISTICAL_INFORMATION_PARTICLES</code>	stats for each particle type
<code>\$STATISTICAL_INFORMATION_GEOMETRY</code>	min/max in X, min/max in Y

The IAEA format specifies a separate header file

A screenshot of a terminal window titled 'images : less'. The window displays the content of a header file in the IAEA format. The text is as follows:

```
$IAEA_INDEX:
1000 // Test header

$TITLE:
PHASESPACE in IAEA format

$FILE_TYPE:
0

$CHECKSUM:
16296786

$RECORD_CONTENTS:
  1 // X is stored ?
  1 // Y is stored ?
  0 // Z is stored ?
  1 // U is stored ?
  1 // V is stored ?
  1 // W is stored ?
  1 // Weight is stored ?
  0 // Extra floats stored ?
  2 // Extra longs stored ?
  1 // Incremental history number stored in the extralong array [ 0]
  2 // LATCH EGS variable stored in the extralong array [ 1]

$RECORD_CONSTANT:
-0.0000 // Constant Z

$RECORD_LENGTH:
```

The IAEA phase space is written in a data file

For each particle, the **binary format** `.IAEAphsp` data file contains:

<code>type</code>	particle type, and sign of direction cosine with respect to Z
<code>E</code>	KINETIC energy of the particle
<code>X</code>	position along X axis (cm)
<code>Y</code>	position along Y axis (cm)
<code>U</code>	direction cosine with respect to X axis
<code>V</code>	direction cosine with respect to Y axis
<code>W</code>	direction cosine with respect to Z axis
<code>WT</code>	statistical weight of particle
<code>n_stat</code>	number of primary histories since previous particle scored
<code>LATCH</code>	value of LATCH variable
<code>ZLAST</code>	photons: Z position of the last interaction; electrons: Z position where electron was set in motion; This is only output if the input variable IZLAST=1

Reading and writing IAEA format phase space files

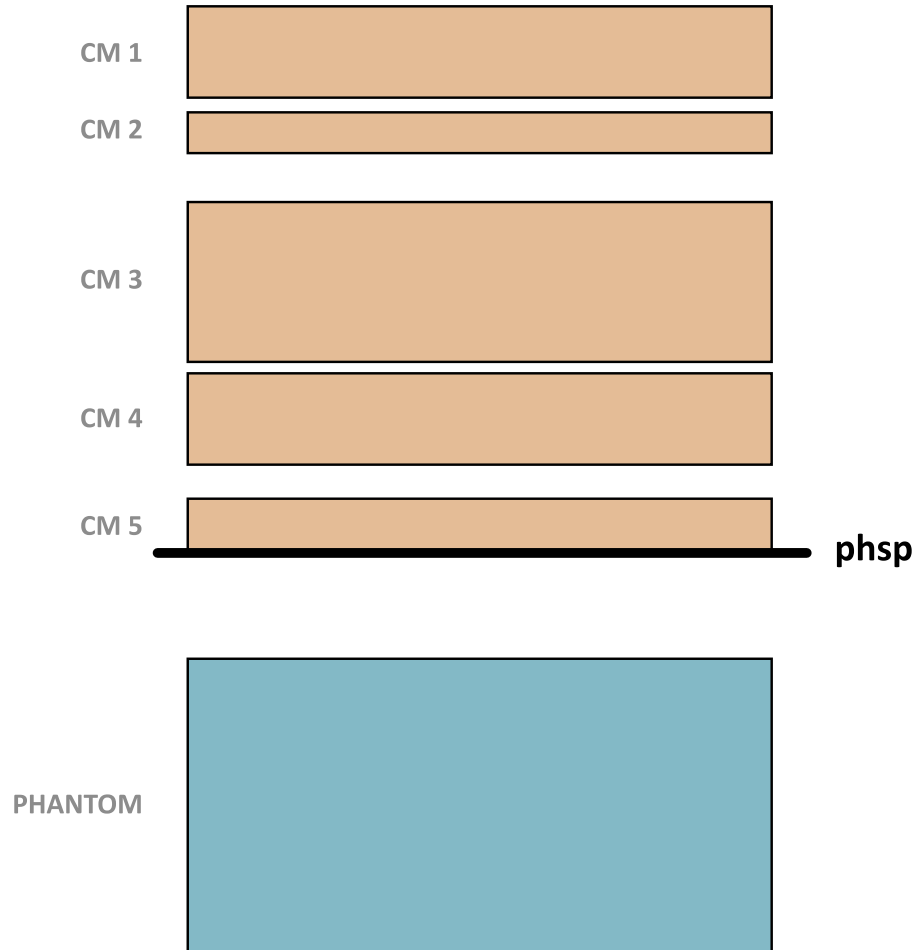
To write IAEA format phase space files from BEAMnrc:

- Set `IO_OPT=4`
- Remember that there are **two** files generated for each scoring plane. The naming scheme is `inputfile.#.IAEAheader` and `inputfile.#.IAEAphsp`, where `#` is the scoring plane number.

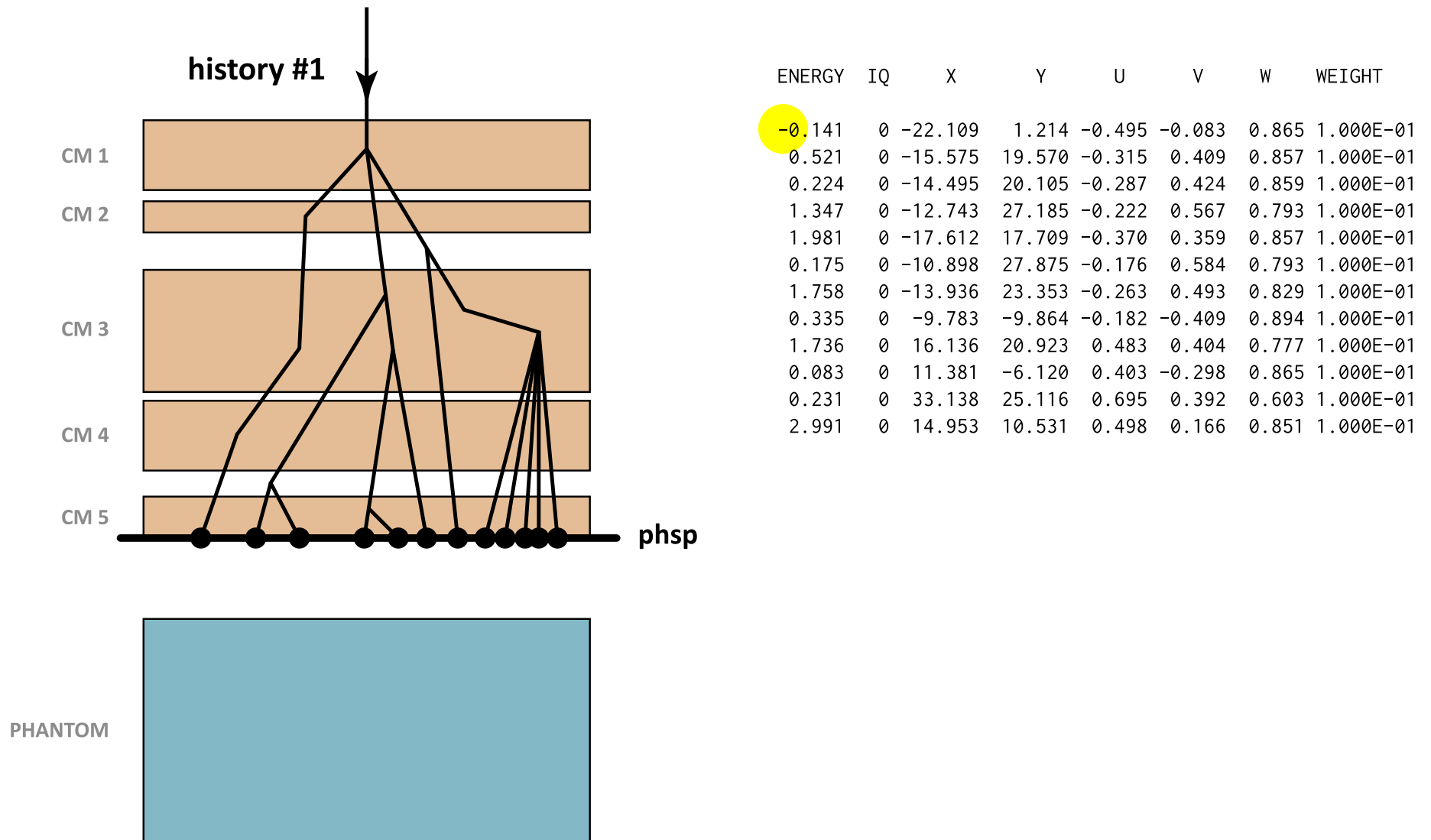
To read IAEA phase space files as sources in BEAMnrc, DOSXYZnrc and other EGSnrc applications:

- Input full name of the data file, including the `.IAEAphsp` extension, and the code takes care of the rest.
- Note that the code assumes that the separate `.IAEAheader` file is in the same directory as the data file.

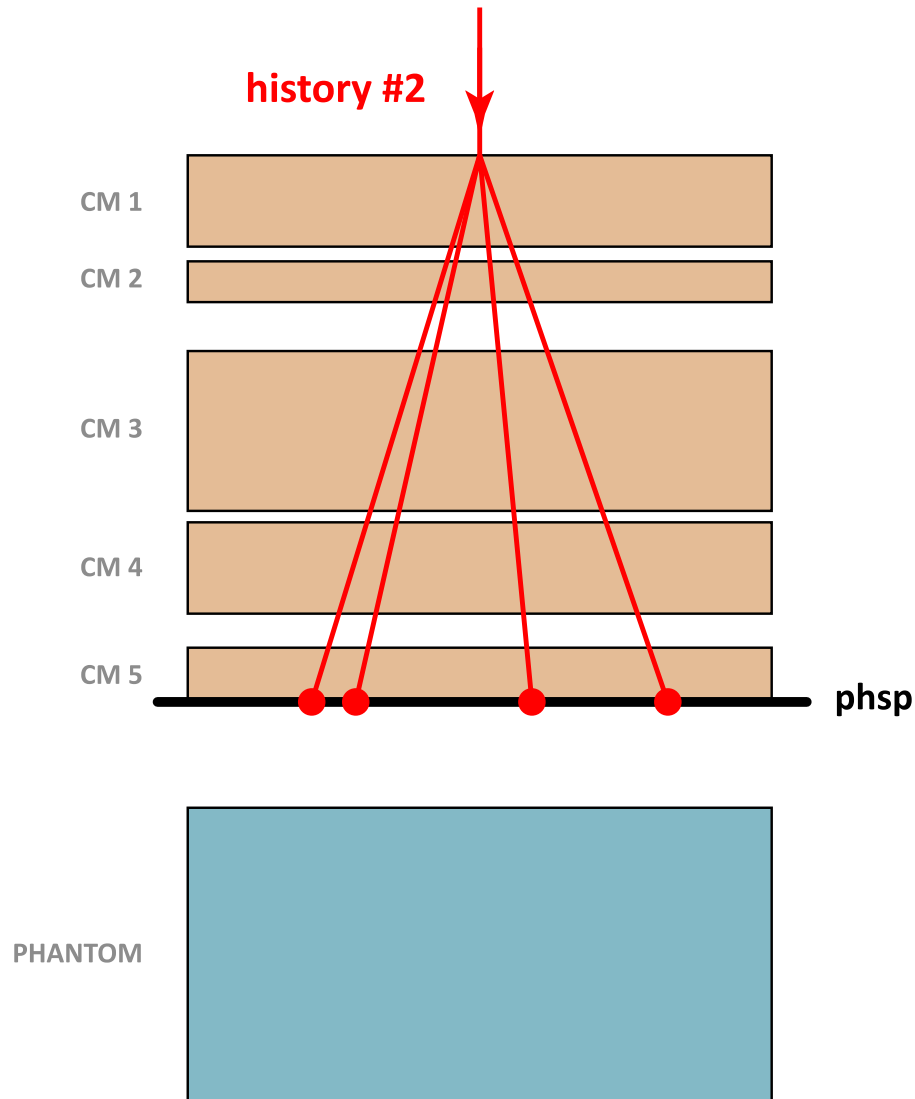
Recycling and restarting



Recycling and restarting

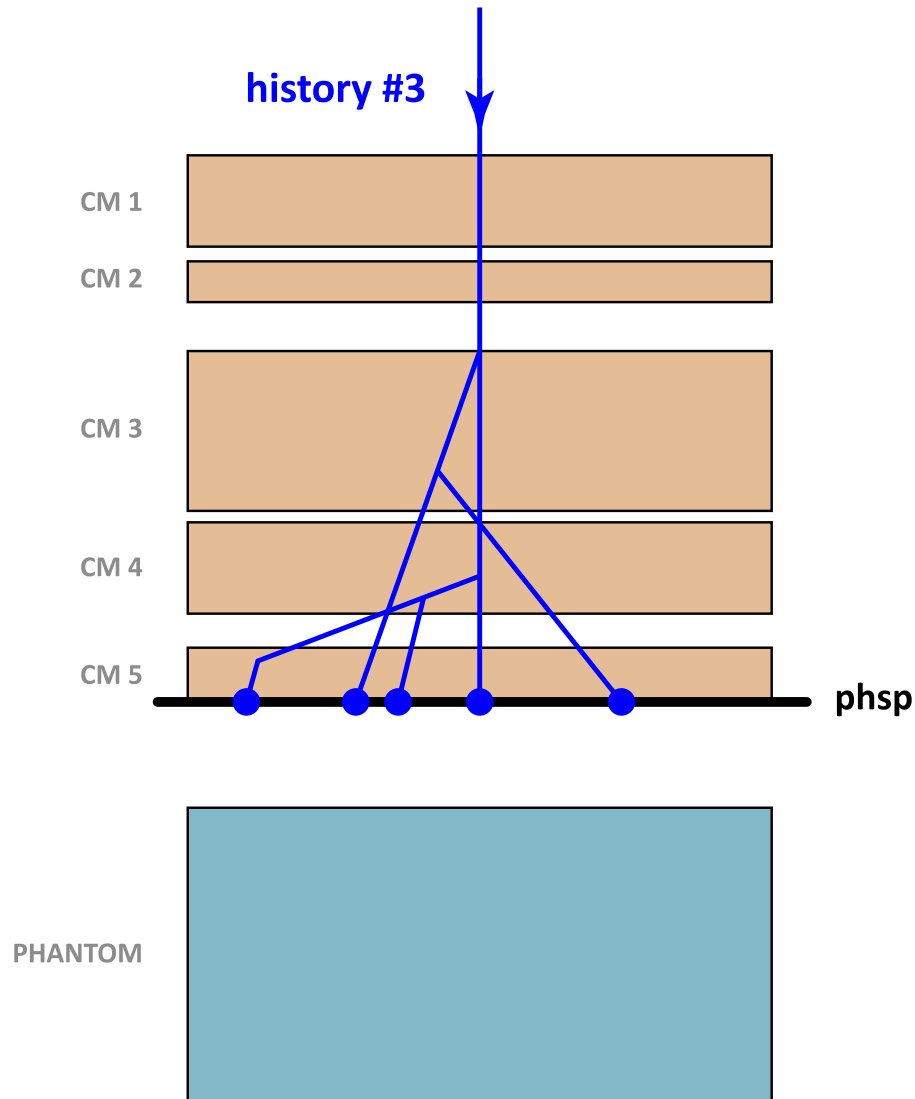


Recycling and restarting



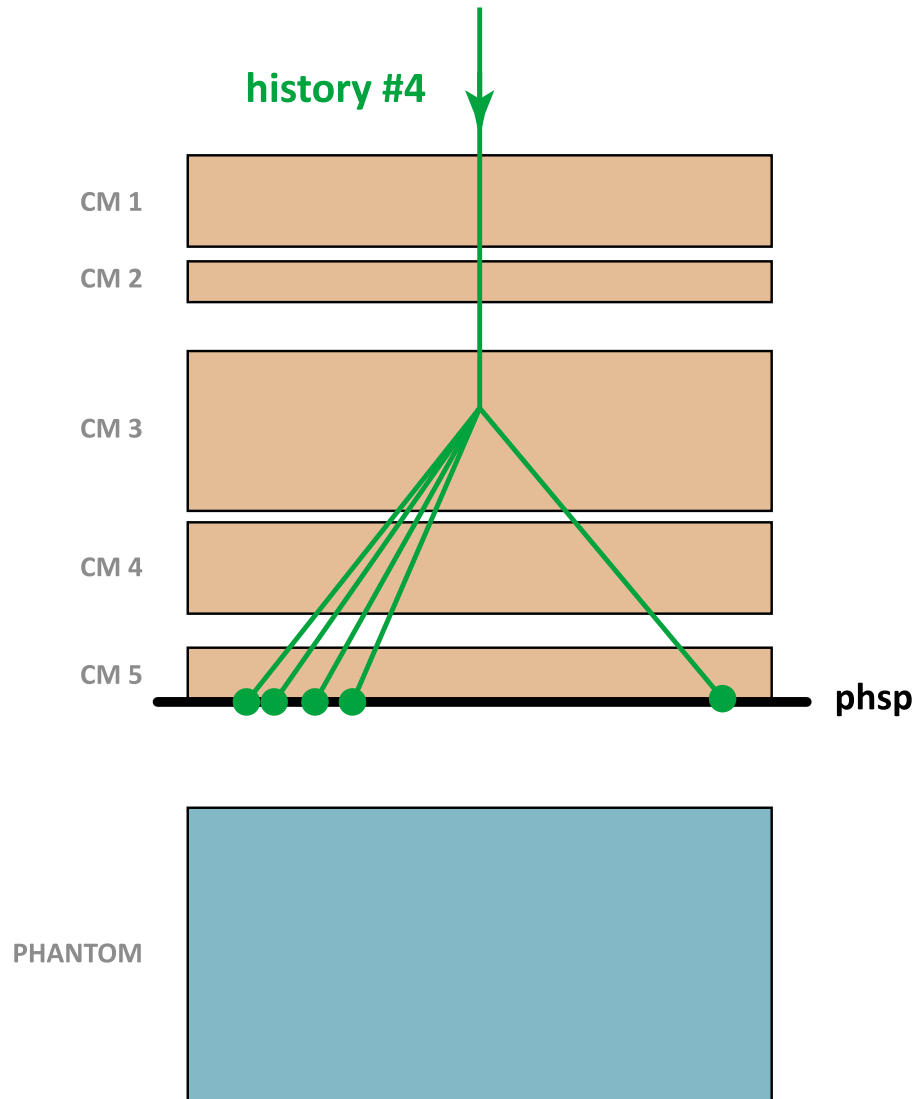
ENERGY	IQ	X	Y	U	V	W	WEIGHT
-0.141	0	-22.109	1.214	-0.495	-0.083	0.865	1.000E-01
0.521	0	-15.575	19.570	-0.315	0.409	0.857	1.000E-01
0.224	0	-14.495	20.105	-0.287	0.424	0.859	1.000E-01
1.347	0	-12.743	27.185	-0.222	0.567	0.793	1.000E-01
1.981	0	-17.612	17.709	-0.370	0.359	0.857	1.000E-01
0.175	0	-10.898	27.875	-0.176	0.584	0.793	1.000E-01
1.758	0	-13.936	23.353	-0.263	0.493	0.829	1.000E-01
0.335	0	-9.783	-9.864	-0.182	-0.409	0.894	1.000E-01
1.736	0	16.136	20.923	0.483	0.404	0.777	1.000E-01
0.083	0	11.381	-6.120	0.403	-0.298	0.865	1.000E-01
0.231	0	33.138	25.116	0.695	0.392	0.603	1.000E-01
2.991	0	14.953	10.531	0.498	0.166	0.851	1.000E-01
-2.273	0	8.072	21.841	0.205	0.538	0.818	1.000E-01
0.259	0	11.563	17.803	0.302	0.447	0.842	1.000E-01
0.385	0	-4.573	-15.985	-0.142	-0.479	0.866	1.000E-01
1.172	0	14.449	18.650	0.365	0.453	0.813	1.000E-01

Recycling and restarting



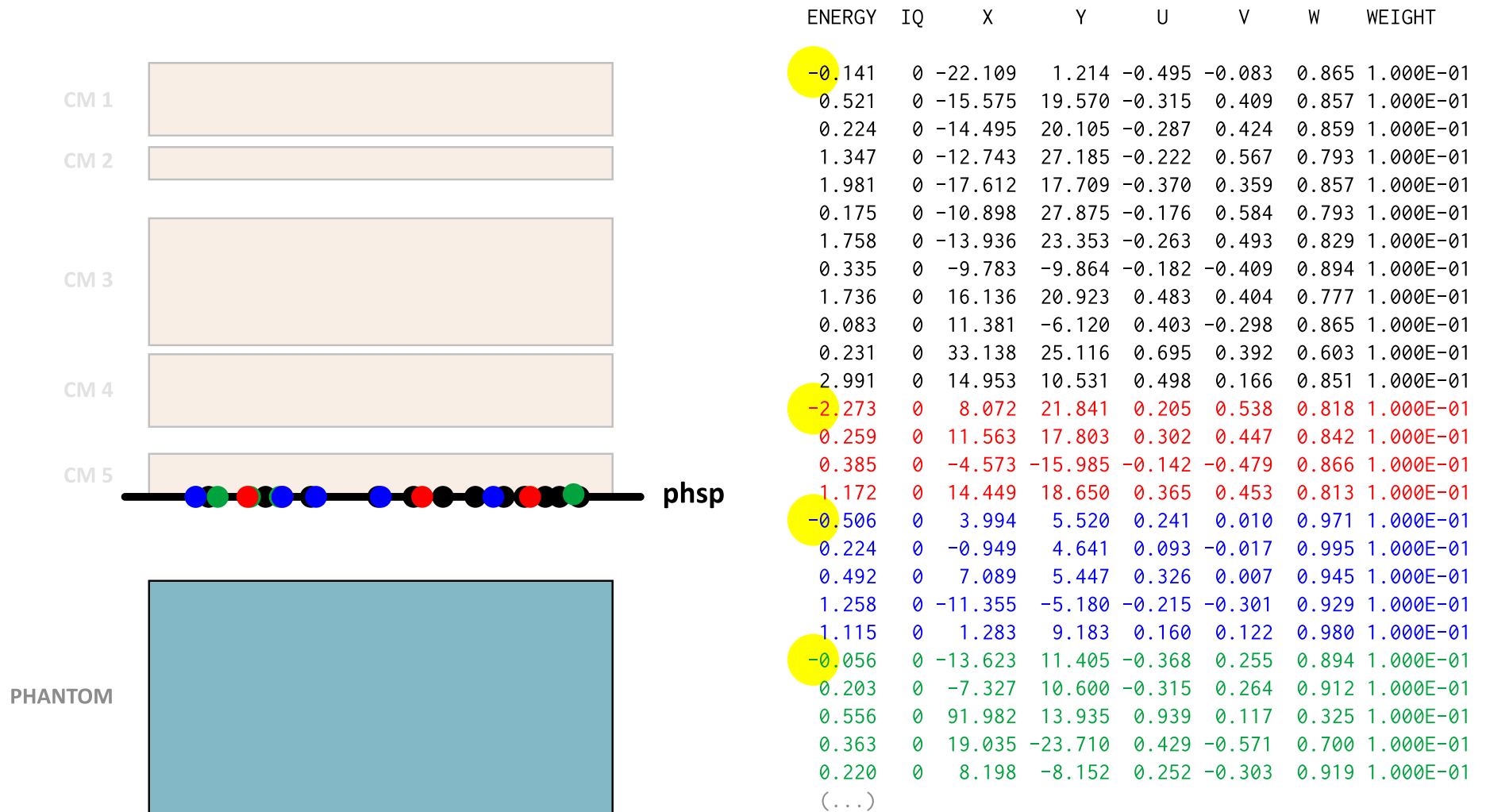
ENERGY	IQ	X	Y	U	V	W	WEIGHT
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0.385	0	-4.573	-15.985	-0.142	-0.479	0.866	1.000E-01
1.172	0	14.449	18.650	0.365	0.453	0.813	1.000E-01
-0.506	0	3.994	5.520	0.241	0.010	0.971	1.000E-01
0.224	0	-0.949	4.641	0.093	-0.017	0.995	1.000E-01
0.492	0	7.089	5.447	0.326	0.007	0.945	1.000E-01
1.258	0	-11.355	-5.180	-0.215	-0.301	0.929	1.000E-01
1.115	0	1.283	9.183	0.160	0.122	0.980	1.000E-01

Recycling and restarting

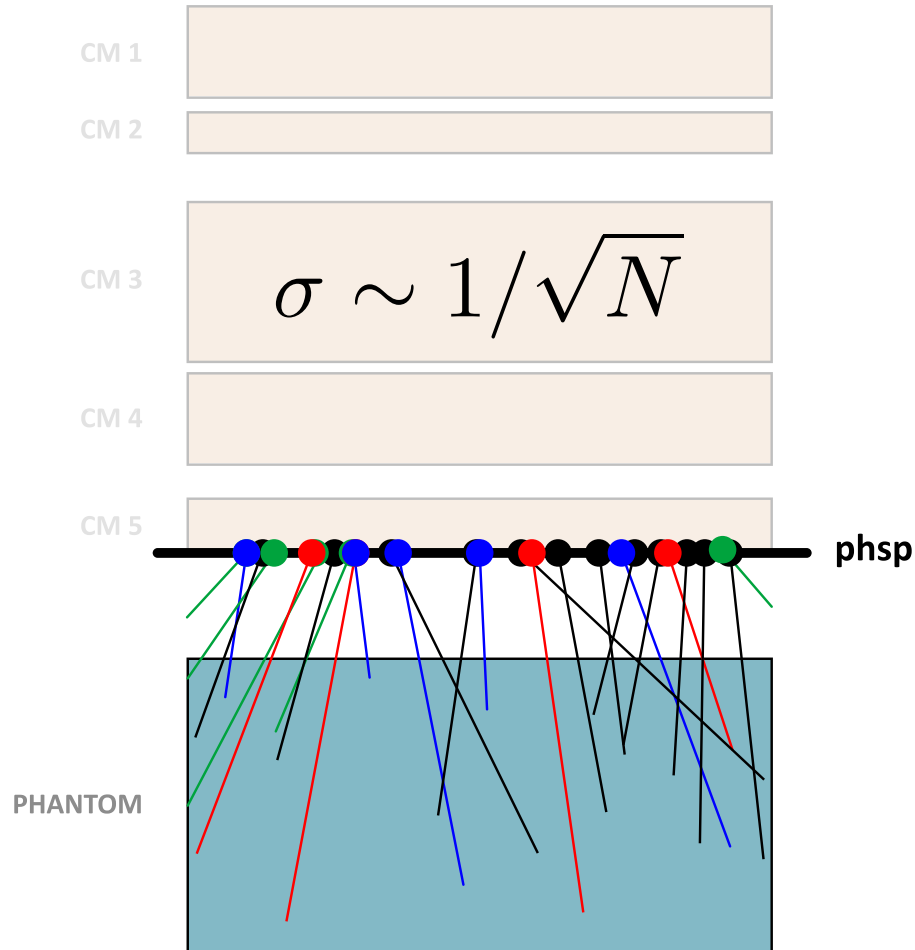


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1.172	0	14.449	18.650	0.365	0.453	0.813	1.000E-01
-0.506	0	3.994	5.520	0.241	0.010	0.971	1.000E-01
0.224	0	-0.949	4.641	0.093	-0.017	0.995	1.000E-01
0.492	0	7.089	5.447	0.326	0.007	0.945	1.000E-01
1.258	0	-11.355	-5.180	-0.215	-0.301	0.929	1.000E-01
1.115	0	1.283	9.183	0.160	0.122	0.980	1.000E-01
-0.056	0	-13.623	11.405	-0.368	0.255	0.894	1.000E-01
0.203	0	-7.327	10.600	-0.315	0.264	0.912	1.000E-01
0.556	0	91.982	13.935	0.939	0.117	0.325	1.000E-01
0.363	0	19.035	-23.710	0.429	-0.571	0.700	1.000E-01
0.220	0	8.198	-8.152	0.252	-0.303	0.919	1.000E-01
(...)							

Recycling and restarting

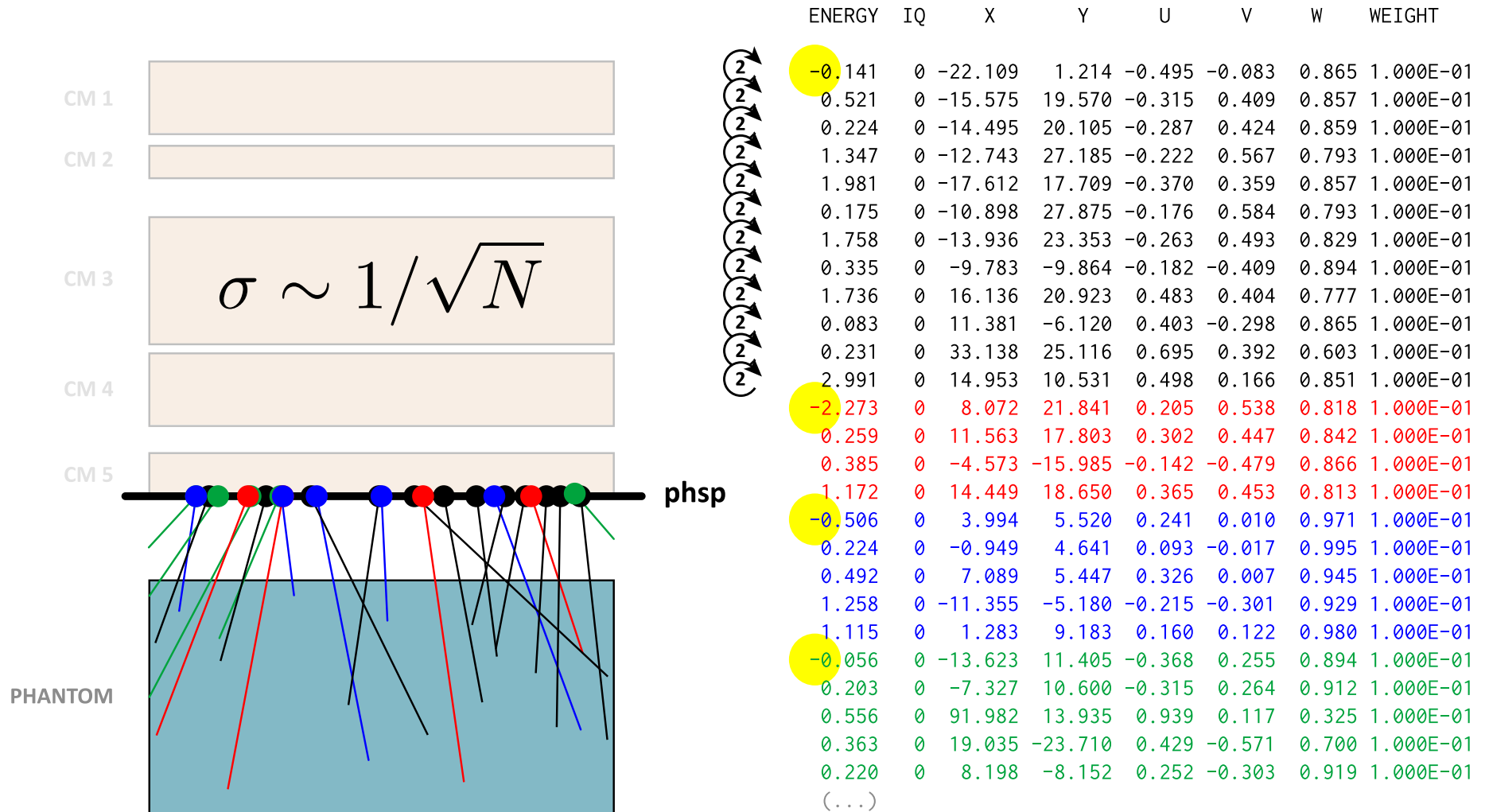


Recycling and restarting

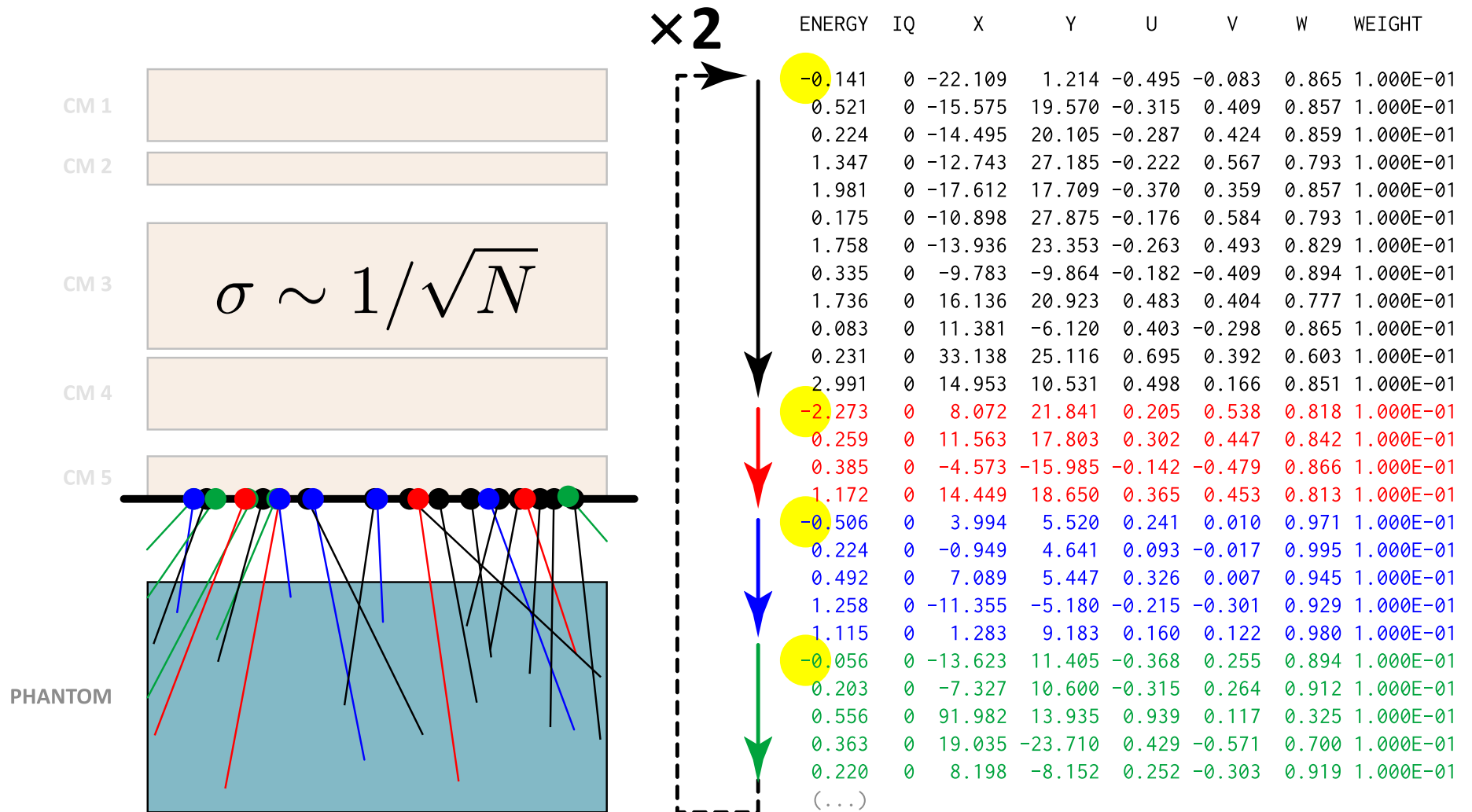


ENERGY	IQ	X	Y	U	V	W	WEIGHT
-0.141	0	-22.109	1.214	-0.495	-0.083	0.865	1.000E-01
0.521	0	-15.575	19.570	-0.315	0.409	0.857	1.000E-01
0.224	0	-14.495	20.105	-0.287	0.424	0.859	1.000E-01
1.347	0	-12.743	27.185	-0.222	0.567	0.793	1.000E-01
1.981	0	-17.612	17.709	-0.370	0.359	0.857	1.000E-01
0.175	0	-10.898	27.875	-0.176	0.584	0.793	1.000E-01
1.758	0	-13.936	23.353	-0.263	0.493	0.829	1.000E-01
0.335	0	-9.783	-9.864	-0.182	-0.409	0.894	1.000E-01
1.736	0	16.136	20.923	0.483	0.404	0.777	1.000E-01
0.083	0	11.381	-6.120	0.403	-0.298	0.865	1.000E-01
0.231	0	33.138	25.116	0.695	0.392	0.603	1.000E-01
2.991	0	14.953	10.531	0.498	0.166	0.851	1.000E-01
-2.273	0	8.072	21.841	0.205	0.538	0.818	1.000E-01
0.259	0	11.563	17.803	0.302	0.447	0.842	1.000E-01
0.385	0	-4.573	-15.985	-0.142	-0.479	0.866	1.000E-01
1.172	0	14.449	18.650	0.365	0.453	0.813	1.000E-01
-0.506	0	3.994	5.520	0.241	0.010	0.971	1.000E-01
0.224	0	-0.949	4.641	0.093	-0.017	0.995	1.000E-01
0.492	0	7.089	5.447	0.326	0.007	0.945	1.000E-01
1.258	0	-11.355	-5.180	-0.215	-0.301	0.929	1.000E-01
1.115	0	1.283	9.183	0.160	0.122	0.980	1.000E-01
-0.056	0	-13.623	11.405	-0.368	0.255	0.894	1.000E-01
0.203	0	-7.327	10.600	-0.315	0.264	0.912	1.000E-01
0.556	0	91.982	13.935	0.939	0.117	0.325	1.000E-01
0.363	0	19.035	-23.710	0.429	-0.571	0.700	1.000E-01
0.220	0	8.198	-8.152	0.252	-0.303	0.919	1.000E-01
(...)							

Recycling and restarting



Recycling and **restarting**

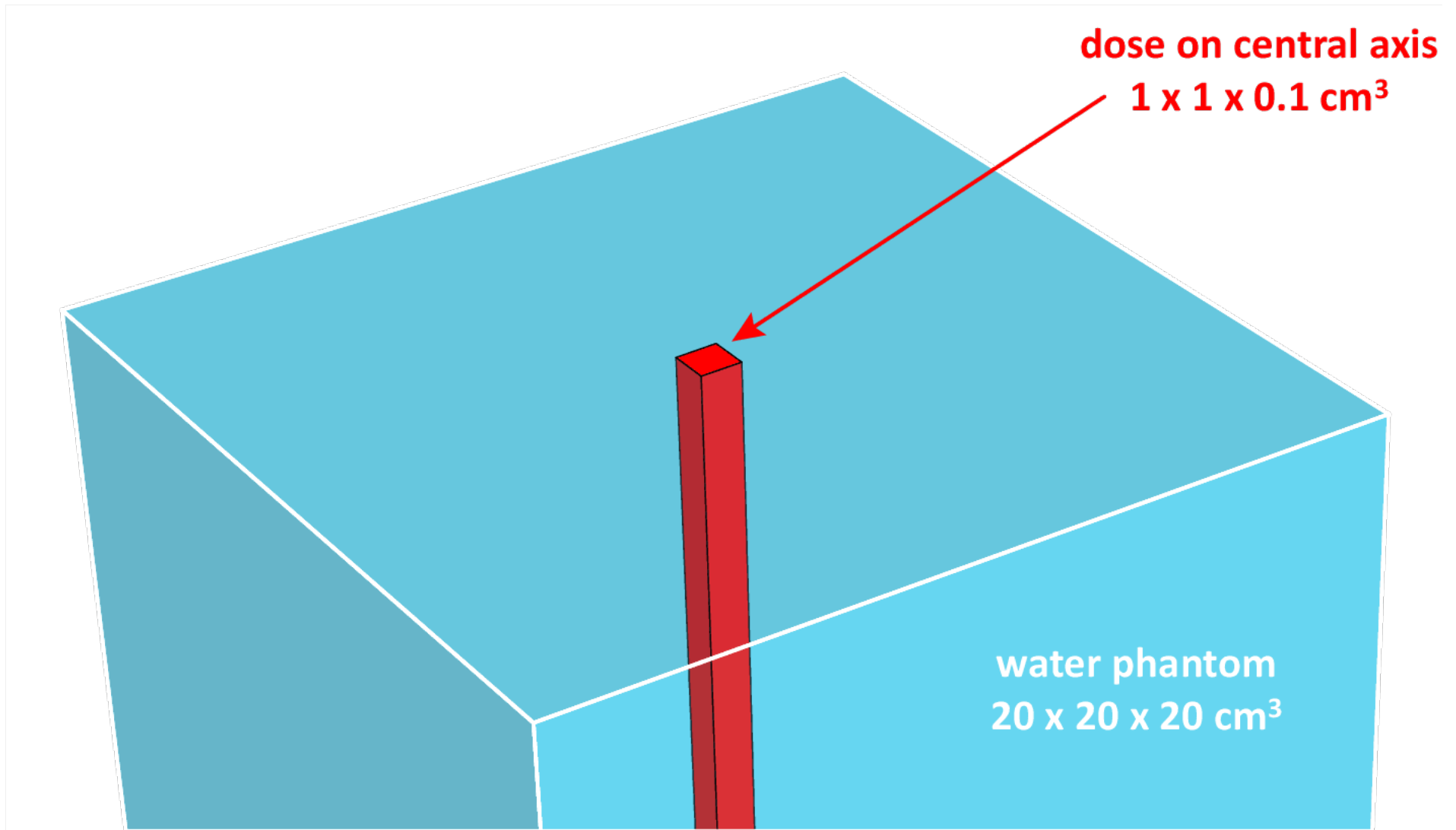


Executive summary (if you *must* reuse particles)

Recycling is good

Restarting is bad

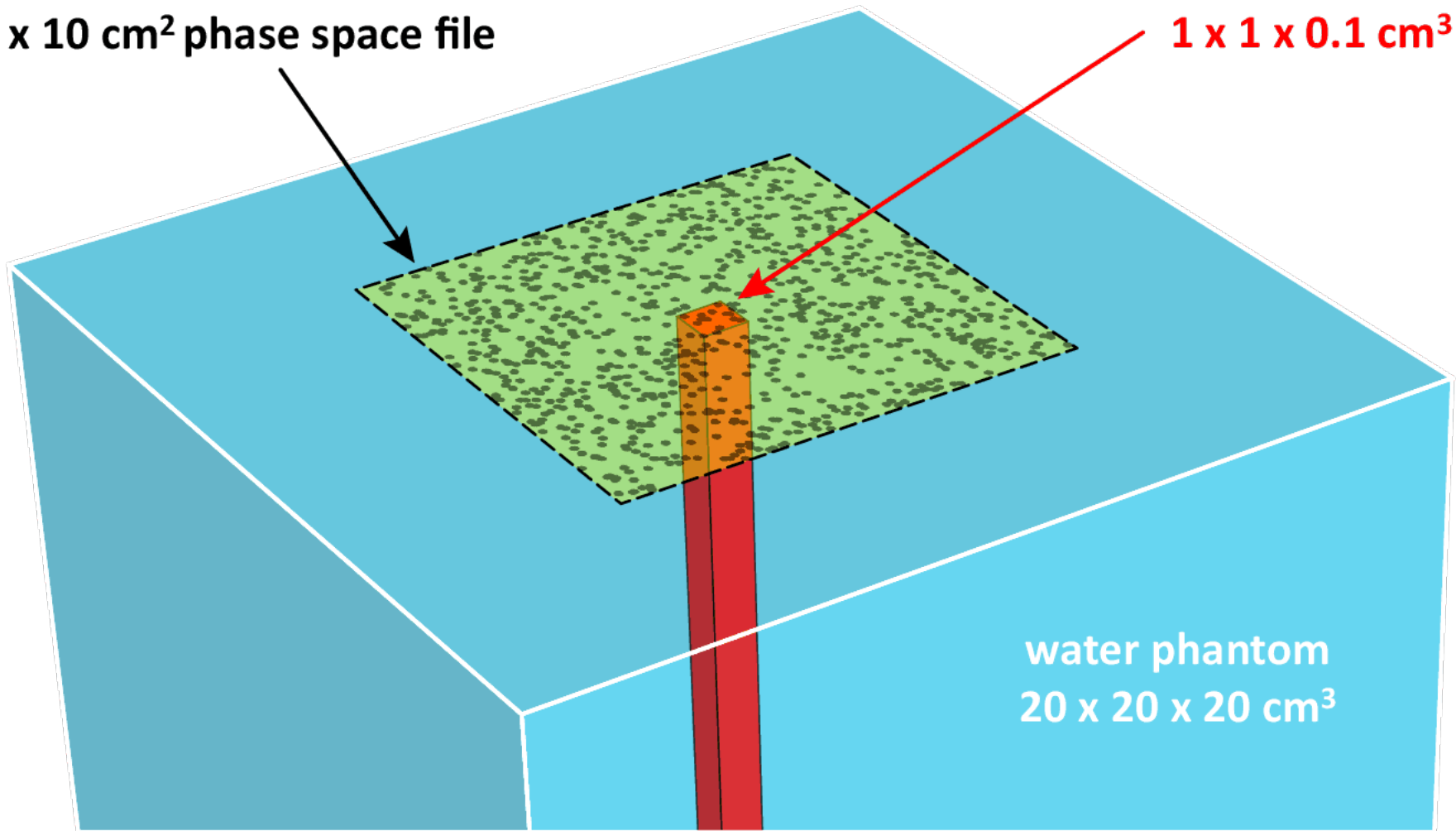
Example: electron depth-dose curve in water



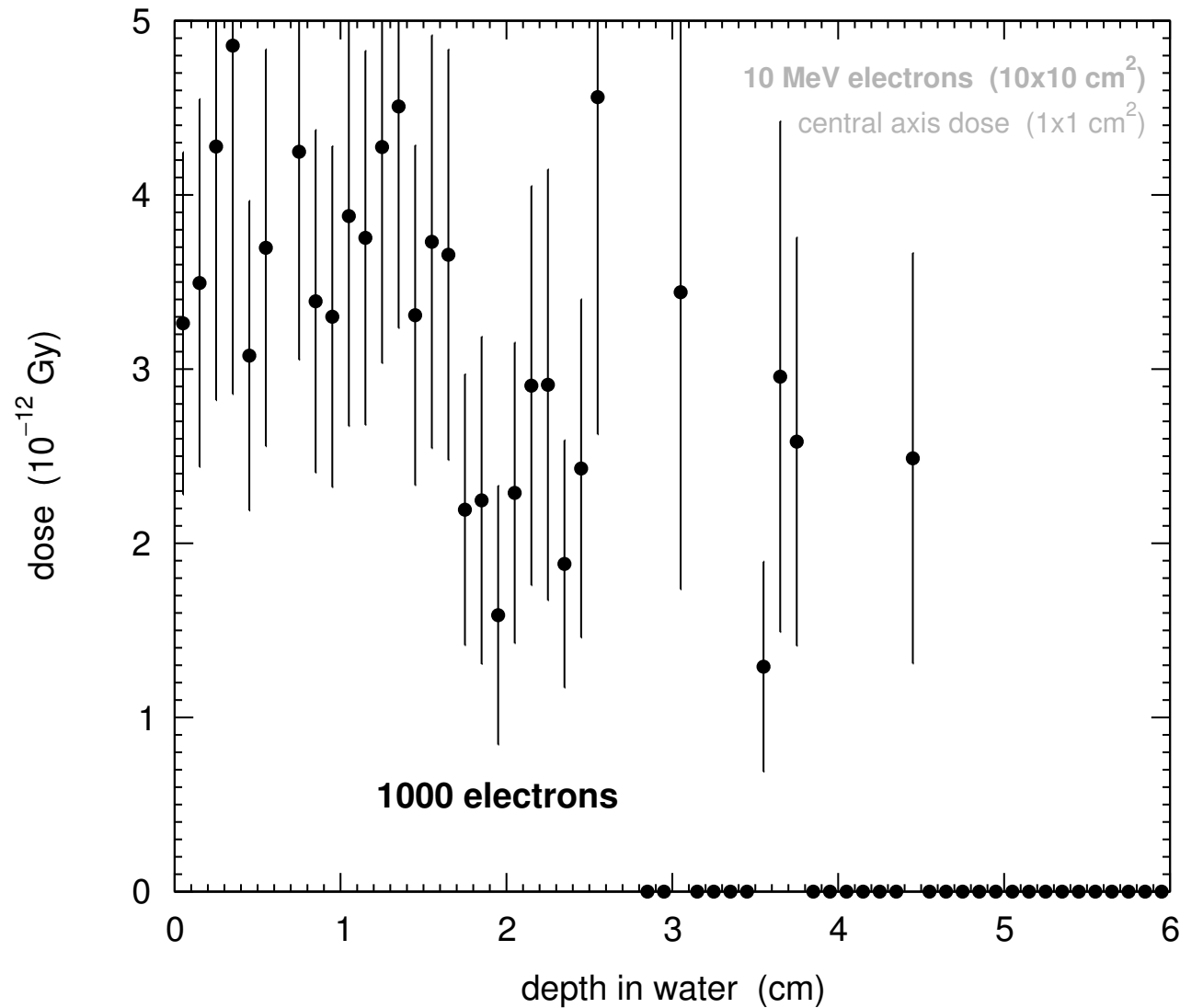
Example: electron depth-dose curve in water

1000 incident 10 MeV electrons
10 x 10 cm² phase space file

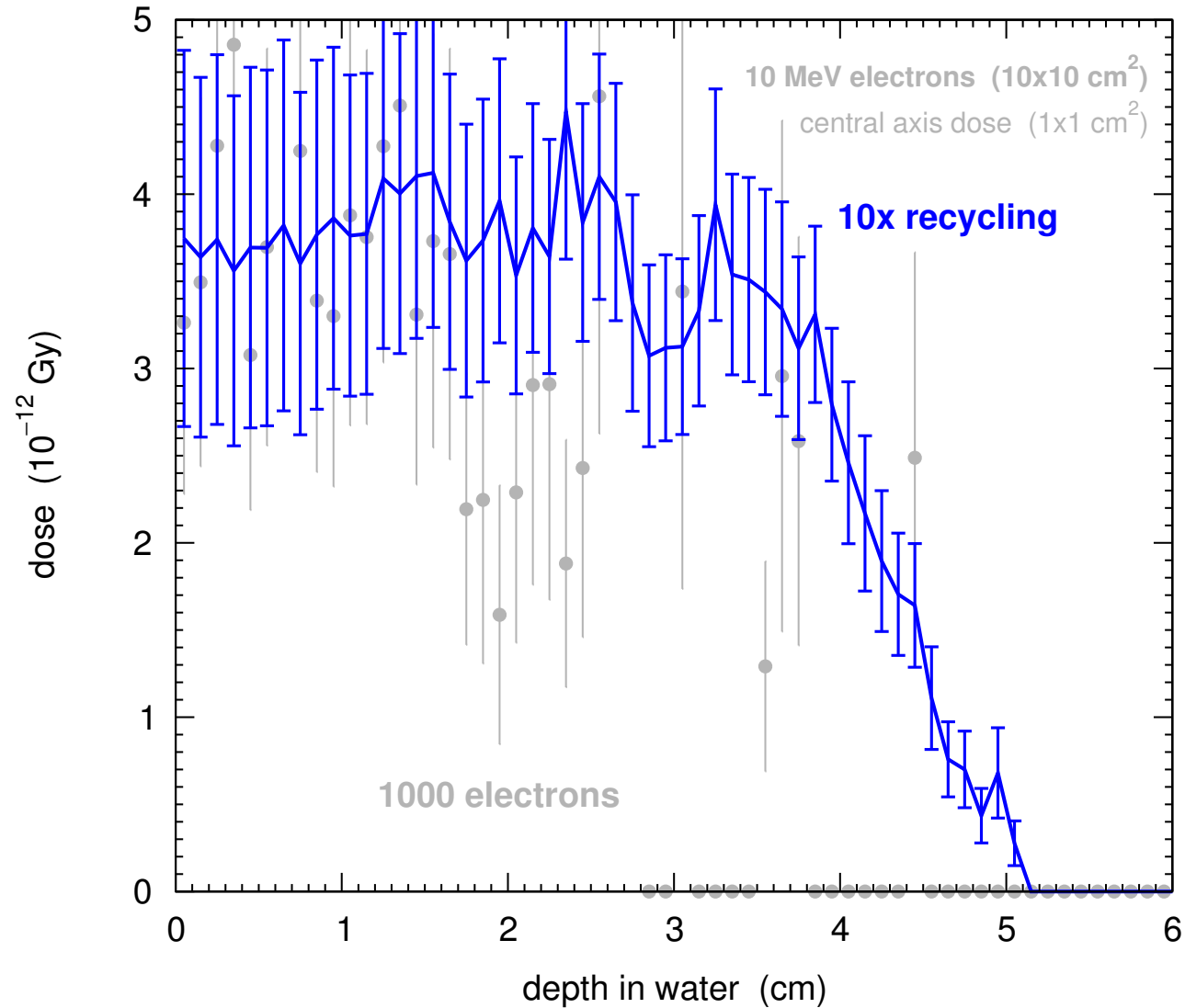
dose on central axis
1 x 1 x 0.1 cm³



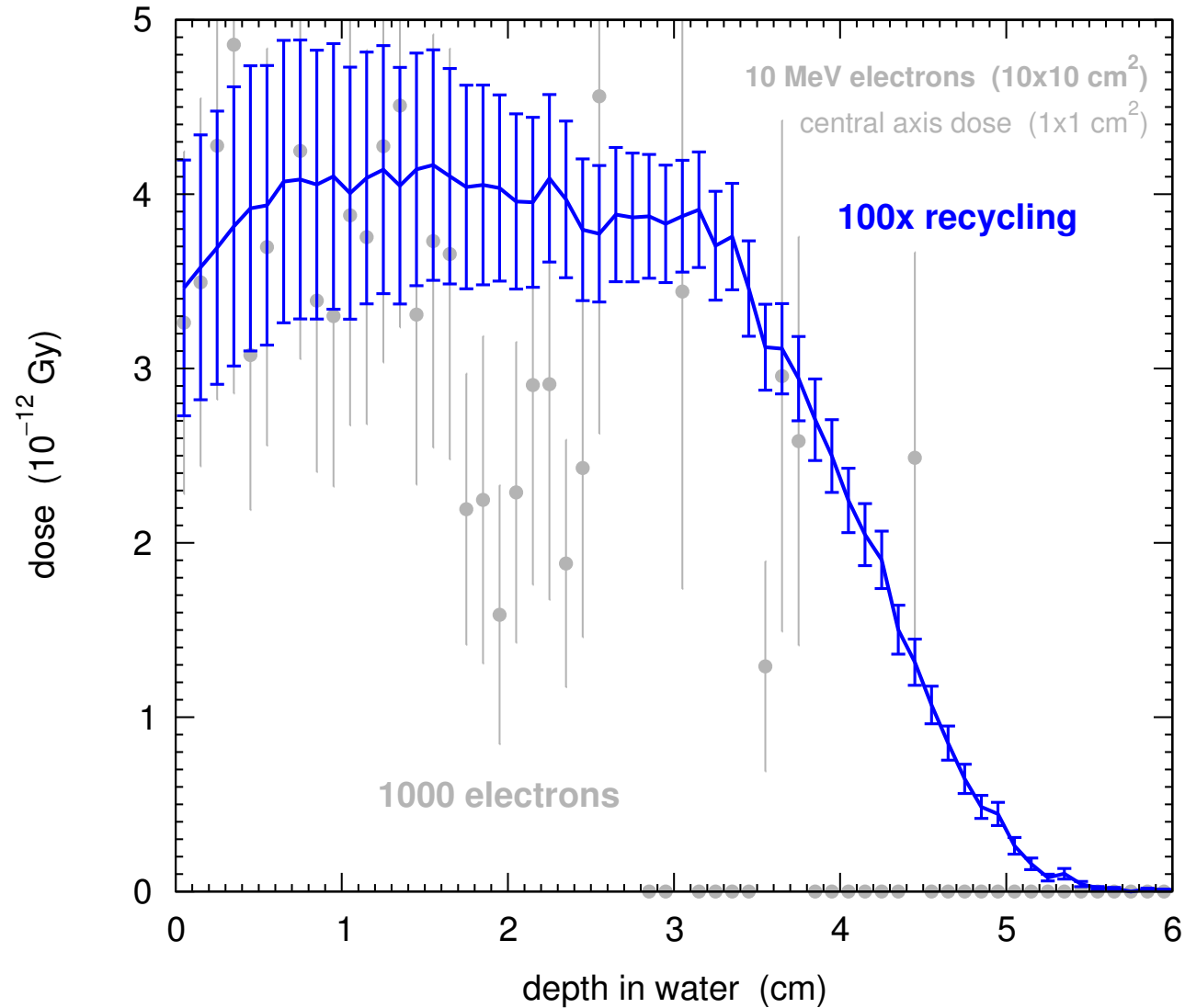
Example: electron depth-dose curve in water



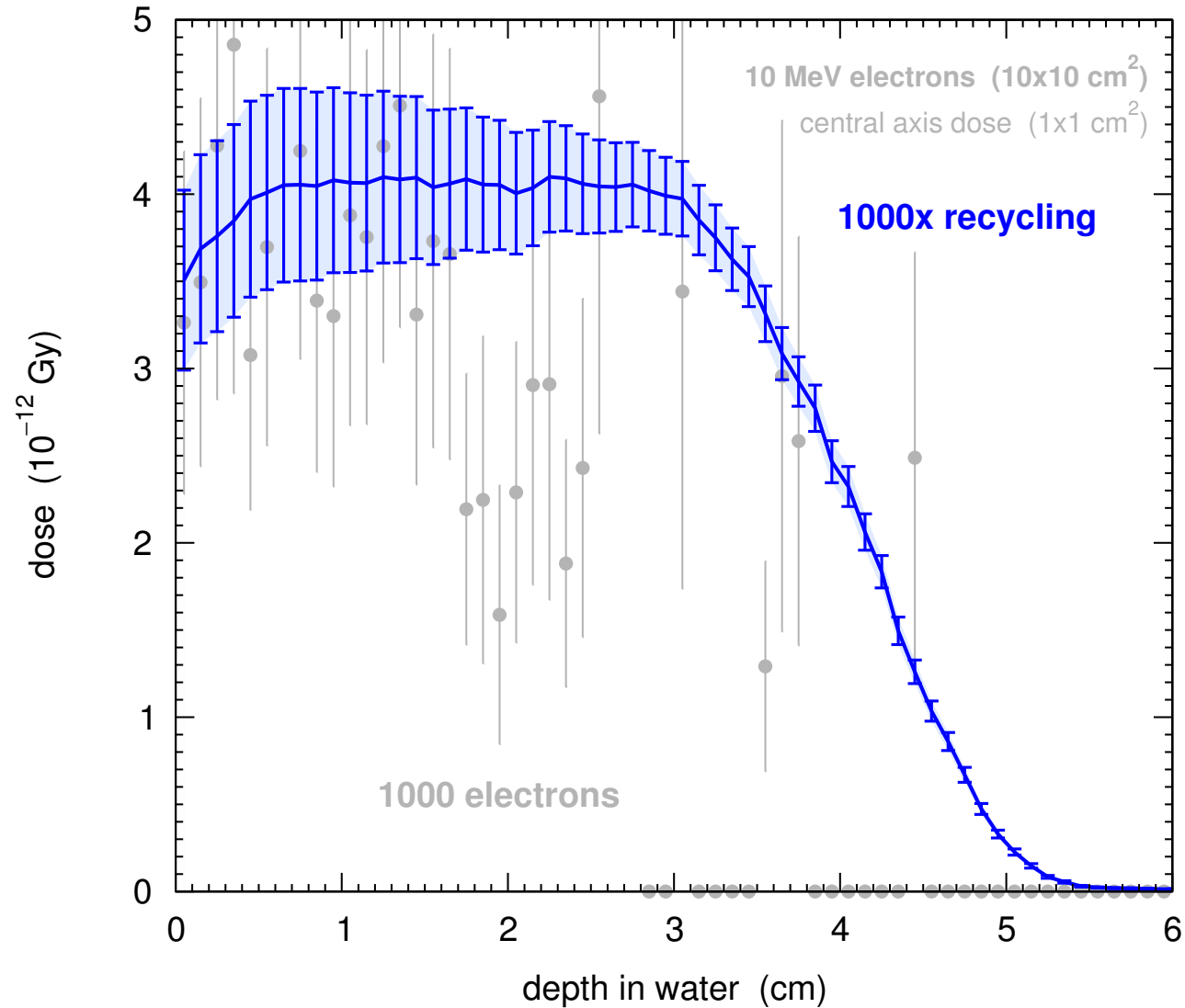
Example: electron depth-dose curve in water



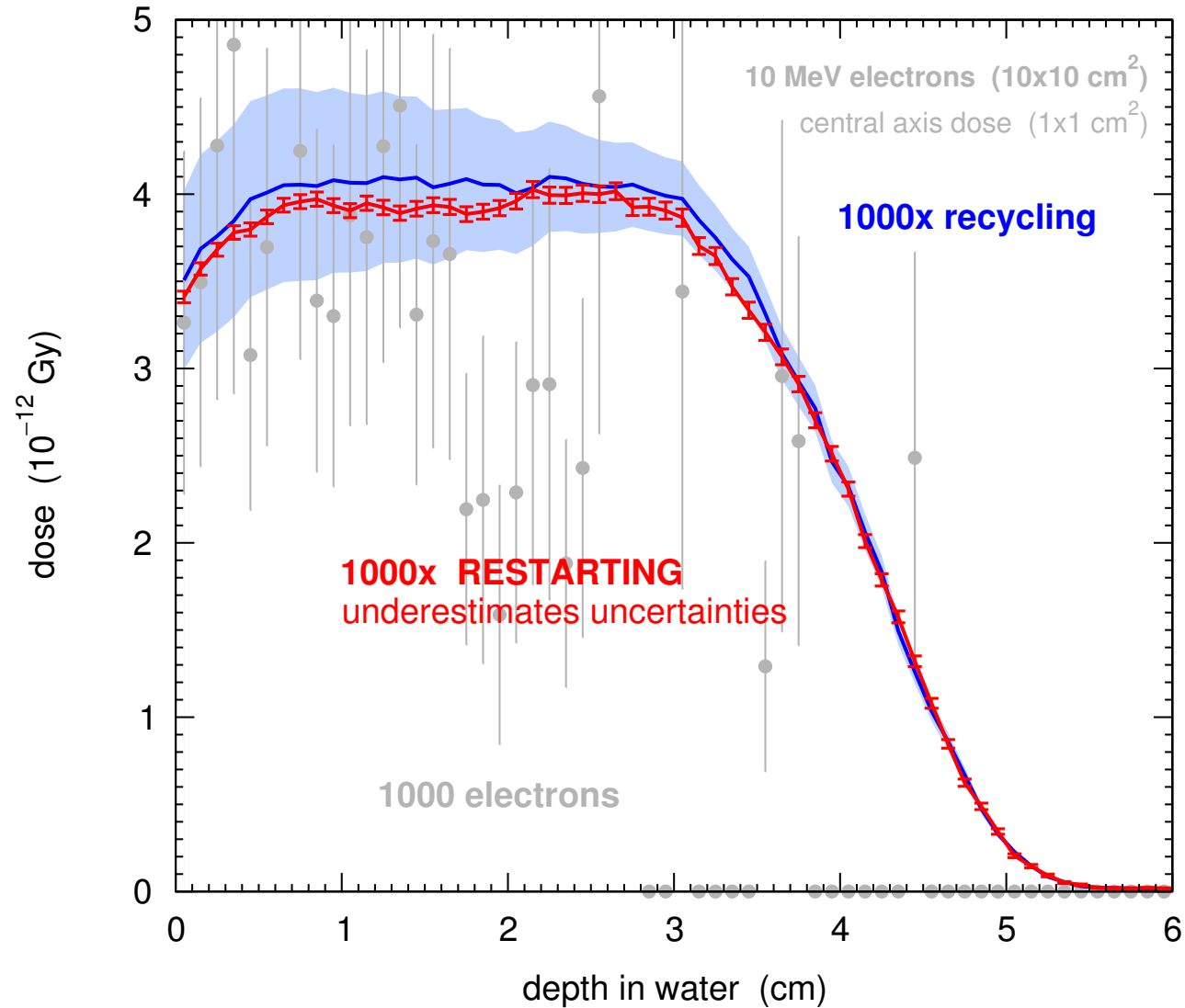
Example: electron depth-dose curve in water



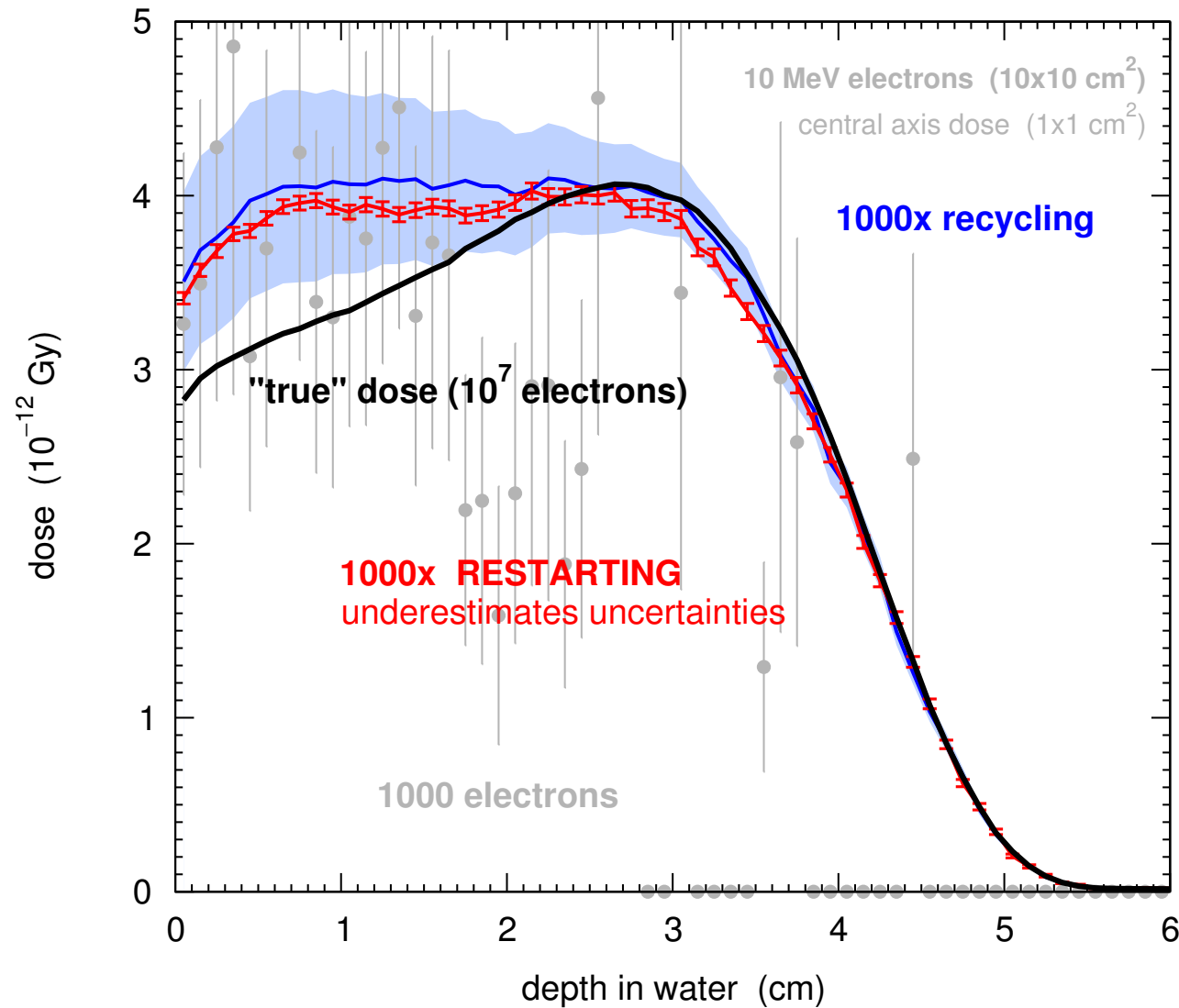
Example: electron depth-dose curve in water



Example: electron depth-dose curve in water



Example: electron depth-dose curve in water



Conclusion

Restarting: stop.

Conclusion

Restarting: stop.

Recycling: slow down...

Conclusion

Restarting: stop.

Recycling: slow down...

More particles: go!