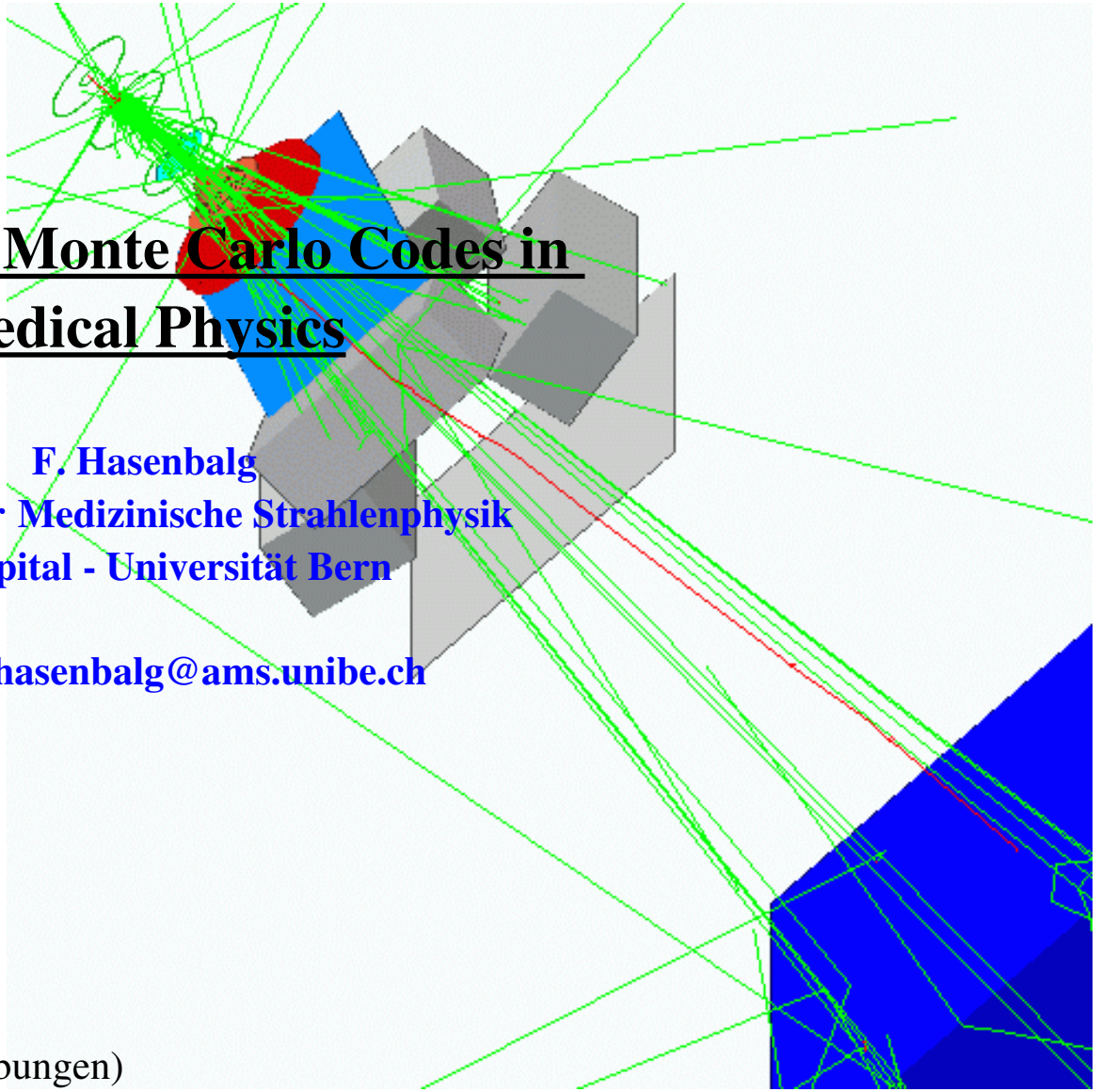
Abteilung für Medizinische Strahlenphysik
Inselspital, Universität Bern, Schweiz
www.ams.unibe.ch

INSELSPITAL
UNIVERSITÄTSSPITAL BERN
HOPITAL UNIVERSITAIRE DE BERNE

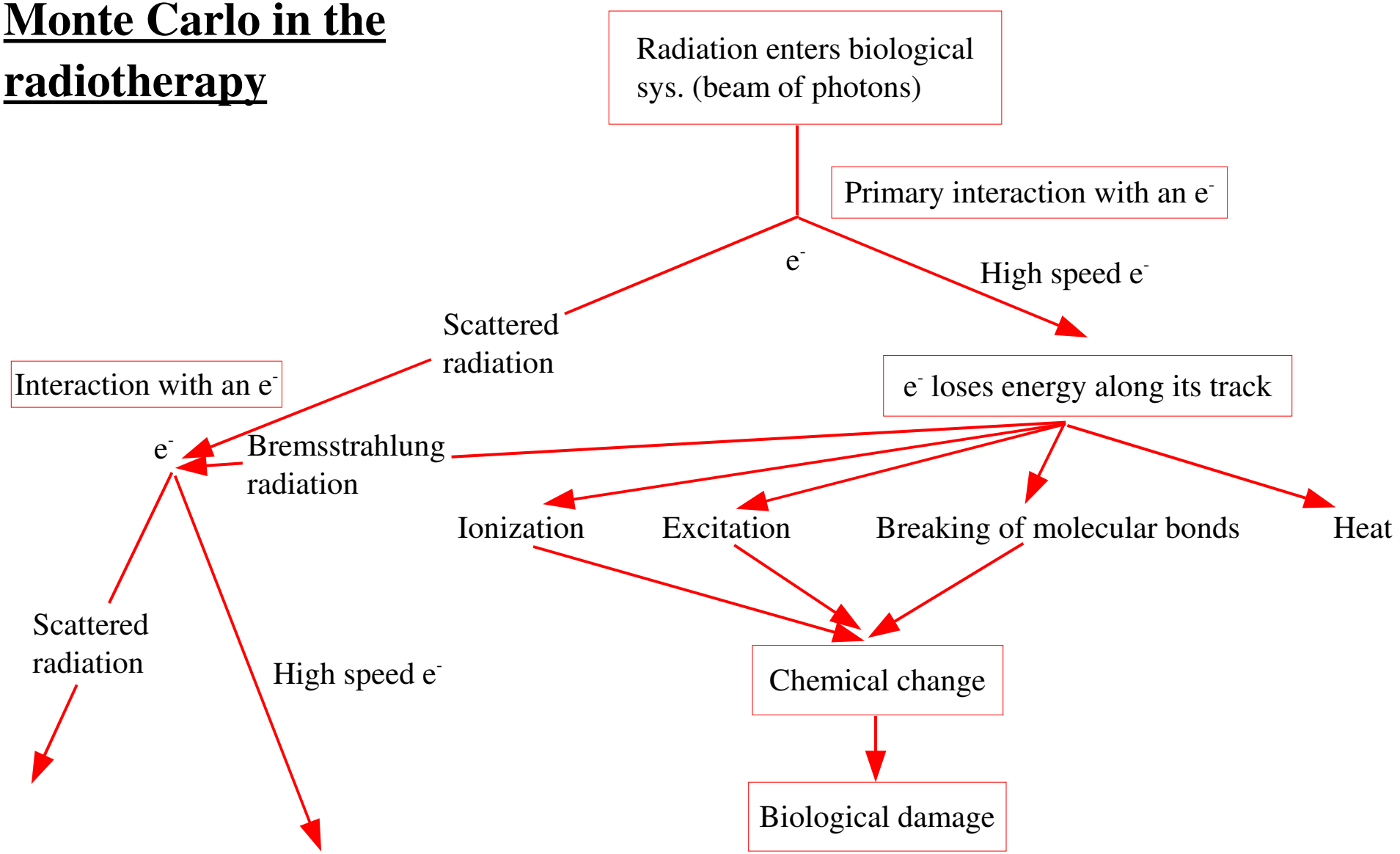


Overview of Monte Carlo Codes in Medical Physics

F. Hasenbalg
Abteilung für Medizinische Strahlenphysik
Inselspital - Universität Bern

e-mail: hasenbalg@ams.unibe.ch

Monte Carlo in the radiotherapy



Monte Carlo available codes

EGS4 (Electron Gamma Shower)	www.slac.stanford.edu/egs Stanford Linear Accelerator
EGSnrc	www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html
BEAMnrc	www.irs.inms.nrc.ca/BEAM/beamhome.html Ionizing Radiation Standards Group National Research Council, Canada
GEANT4 (GEometry And Tracking)	geant4.web.cern.ch/geant4 www.ge.infn.it/geant4/lowE Conseil Européen pour la Recherche Nucléaire, CERN
MCNP (Monte Carlo N-Particle)	laws.lanl.gov/x5/MCNP/index.html Los Alamos National Laboratories
PENELOPE	www.nea.fr/abs/html/nea-1525.html
PEREGRINE	www.llnl.gov/peregrine Lawrence Livermore National Laboratory
ITS (Integrated Tiger Series)	www.nea.fr/abs/html/ccc-0467.html Sandia National Laboratories
VMC (Voxel Monte Carlo)	Ionizing Radiation Standards Group National Research Council, Canada
eMC	Varian medical systems

Physics processes

What processes should we simulate?
Leptonic processes (e^-, e^+, muons, etc), hadronic processes (protons, heavy ions, kaons, etc)

Typical list for electromagnetic interactions (cross sections per atom)

- γ: Coherent scattering (Rayleigh scattering, ~$Z^{2.5}$)
  - Photoelectric effect (~$Z^{4.5}$)
    - Auger electrons
    - Characteristic X-rays
  - Compton scattering (incoherent scattering, ~Z)
  - Pair production with screening (in the field of a nucleus, ~Z^2)
    - Triplet production (pair prod. in the field of an atomic e^-, ~Z)

- e^-, e^+: Continuous energy loss through collisions with atomic e^- (~Z)
  - Møller scattering ($e^- e^-$)
  - Bhabha scattering ($e^+ e^-$)

  ] Delta e^-
  - Bremsstrahlung production (~Z^2)
  - Annihilation (positron annihilation ~Z)
  - Multiple scattering: elastic Coulomb scattering from nuclei
    - Molière theory for small angles < 30°

Photon transport

The principle of MC calculations can be easily exemplified by the selection of the path length of a photon.

A photon of energy E and linear attenuation coefficient $\mu(E)$, has a probability of interaction between s and s + ds is given by,

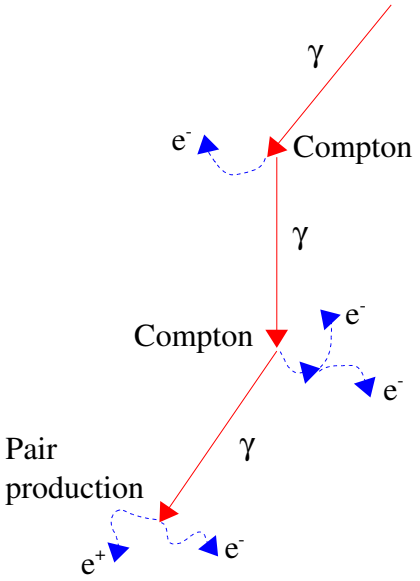
$$f(s)\,ds = \mu(E)\,e^{-\mu(E)s}\,ds$$

Its cumulative distribution function,

$$F(s) = \int_0^s \mu(E)\,e^{-\mu(E)s'}\,ds' = 1 - e^{-\mu(E)s}$$

will be uniformly distributed in the interval (0,1) and given a random variable ξ also uniformly distributed between 0 and 1, s can be derived by direct inversion,

$$s = F^{-1}(\xi) = -\frac{1}{\mu(E)}\ln(1-\xi)$$



Here ξ is obtained from a **random number generator**.

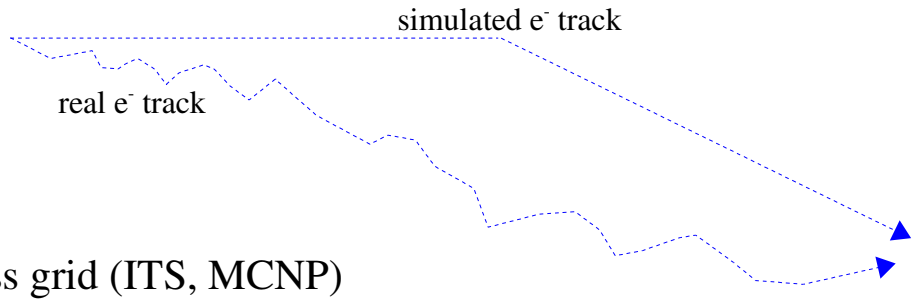
After s has been determined in this way, a second random number is sampled to establish what type of interaction (photoelectric effect, Compton scattering or pair production) took place.

Finally, all secondary particles are followed and the deposited energy in each volume element added.

Ref: Fippel, M., Grundlagen der Monte-Carlo-Methode für die Dosisberechnung in der Strahlentherapie. *Z. Med. Phys.*, **11** (2001) 485 – 498.

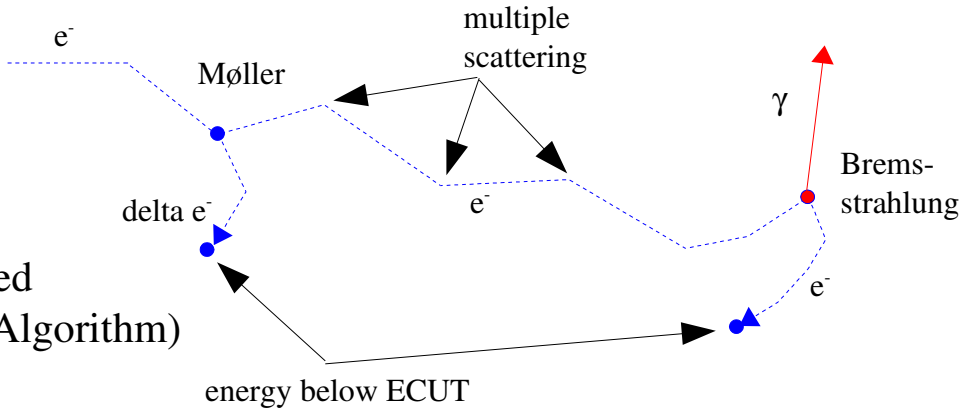
Electron transport

Condensed history: large number of transport and collision processes are "condensed" to a single electron step using appropriate multiple scattering distributions.



Class I: particles move in a predetermined energy loss grid (ITS, MCNP)

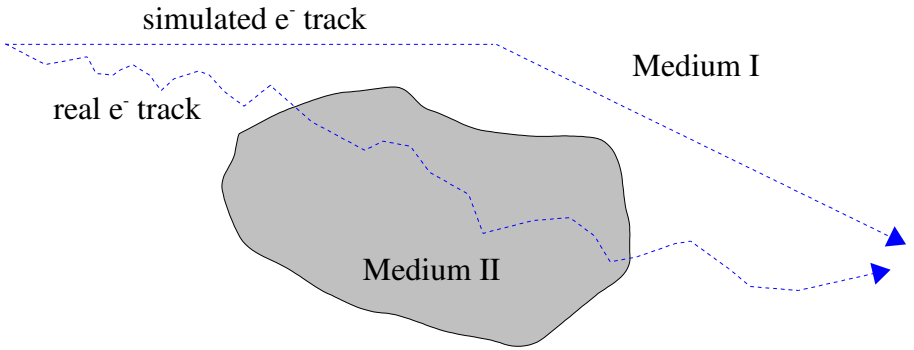
Class II: bremsstrahlung and delta particles above a given energy threshold are treated explicitly by creation and transport (EGS4, EGSnrc, Geant4)



Brief history of names:

EGS4 Standard
Presta (Parameter Reduced Electron Step Transport Algorithm)

EGSnrc Presta-II (Extension of Molière theory)



Boundary crossing algorithm: a simulated e⁻ track is located only in medium I, but a real track could have gone through medium II affecting the length of the track, angle and energy deposition. The BCA should avoid this artifact.

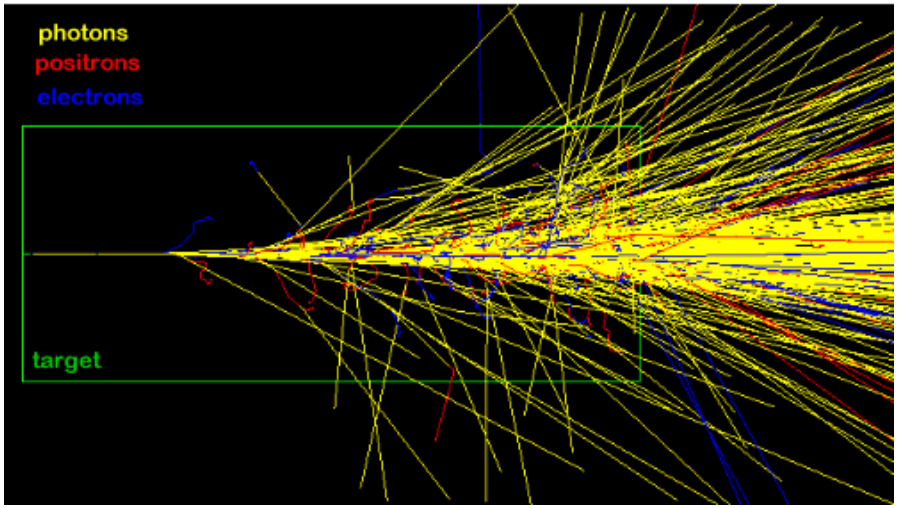
Ref: Kawrakow, I., Accurate condensed history Monte Carlo simulation of electron transport. I. EGSnrc, the new EGS4 version. *Med. Phys.*, **27** (2000) 485 – 498.

Electron Gamma Shower EGS

EGS4, standard distribution

Stanford Linear Accelerator (SLAC)

Massive shower in a tungsten cylinder (outlined in green) produced by a single 10 GeV incident electron.



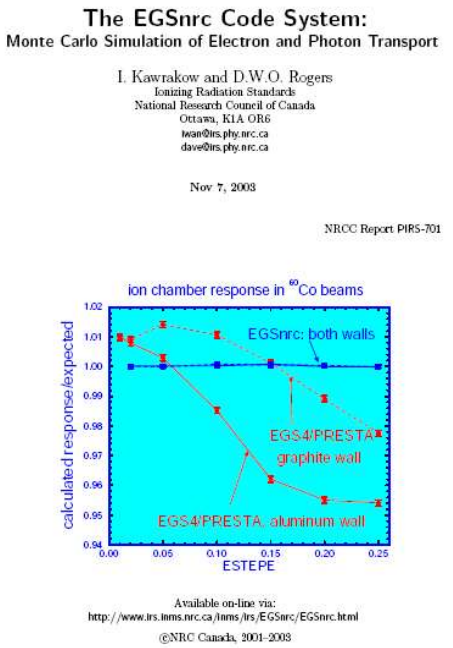
EGSnrc

gold standard for clinical radiation dosimetry

www.sao.nrc.ca/inms/irs/EGSnrc/EGSnrc.html

The EGSnrc system is a package for the Monte Carlo simulation of coupled electron- photon transport. Its current energy range of applicability is considered to be 1keV – 10 GeV.

EGSnrc is an extended and improved version of the EGS4 package originally developed at SLAC. It incorporates many improvements in the implementation of the condensed history technique for the simulation of charged particle transport and better low energy cross sections.


The EGSnrc Code System:
Monte Carlo Simulation of Electron and Photon Transport

I. Kawrakow and D.W.O. Rogers
Ionizing Radiation Standards
National Research Council of Canada
Ottawa, K1A OR6
iwan@irs.phy.nrc.ca
dave@irs.phy.nrc.ca

Nov 7, 2003

NRCC Report PIRS-701

Ref: Kawrakow, I. and D. W. O. Rogers, The EGSnrc Code System: Monte Carlo Simulation of Electron and Photon Transport. *Med.NRCC Report PIRS-701, 2003.*

www.irs.inms.nrc.ca/inms/irs/EGSnrc/EGSnrc.html

EGSnrc relevant parameters

Global electron cutoff energy, ECUT: ECUT defines the global cutoff energy for electron transport in MeV. As soon as an electron's total energy falls below the cutoff energy, its history is terminated and its energy deposited in the current region. For therapy beams, ECUT can be quite high since low energy electrons contribute little to dose in phantom (e.g. ECUT=0.700 MeV but much higher is also possible). However, if the dose in the monitor chamber is an important part of the calculation, lower values of ECUT may be required.

Global photon cutoff energy, PCUT: PCUT defines the global cutoff energy for photon transport in MeV. The exact value of PCUT is not critical in the sense that low values do not take much more time. A value of 0.01 MeV should generally be used.

Maximum step size, SMAX: Global maximum step-size restriction for electron transport (in cm).

Maximum fractional energy loss/step, ESTEPE: Global option. The default is 0.25 (25%).

Boundary crossing algorithm (BCA_algorithm): Two selections possible: EXACT and PRESTA-I. PRESTA-I means with lateral correlations turned off at a distance given by `Skin depth for BCA' from the boundary. EXACT means the algorithm will cross boundaries in a single scattering (SS) mode, the distance from a boundary at which the transition to SS mode is made is determined by `Skin depth for BCA'.

Skin depth for BCA (skindepth_for_BCA): If Boundary crossing algorithm=PRESTA-I then this is the distance from the boundary (in elastic MFP) at which lateral correlations will be switched off.
If Boundary crossing algorithm=EXACT then this is the distance from the boundary (in elastic MFP) at which the algorithm will go into single scattering mode and defaults to 3 mfp.

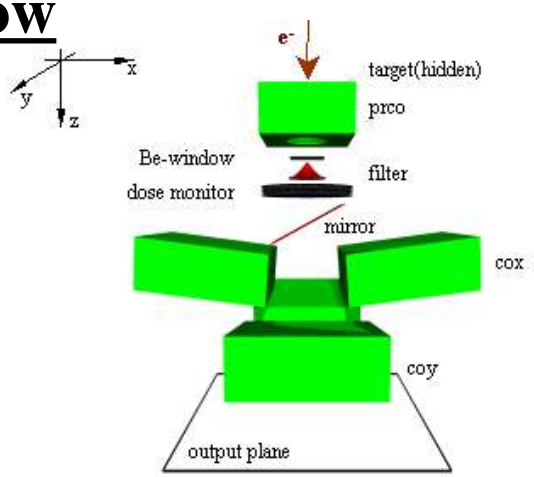
Electron-step algorithm (transport_algorithm): Determines the algorithm used to take into account lateral and longitudinal correlations in a condensed history step.

Spin effects (spin_effects): Turns off/on spin effects for electron elastic scattering.

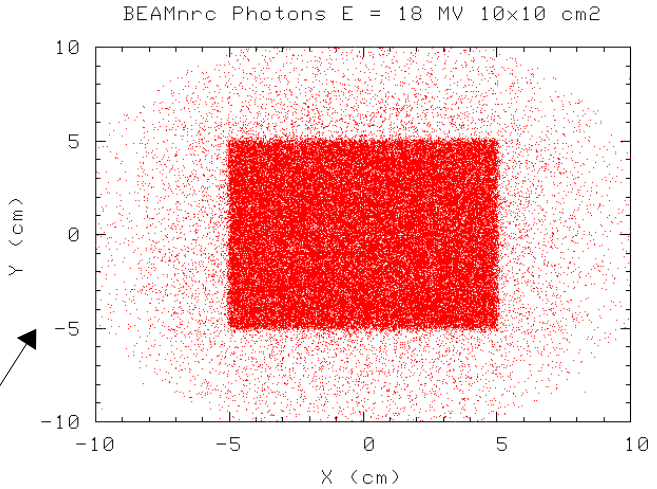
BEAMnrc work flow

EGSnrc

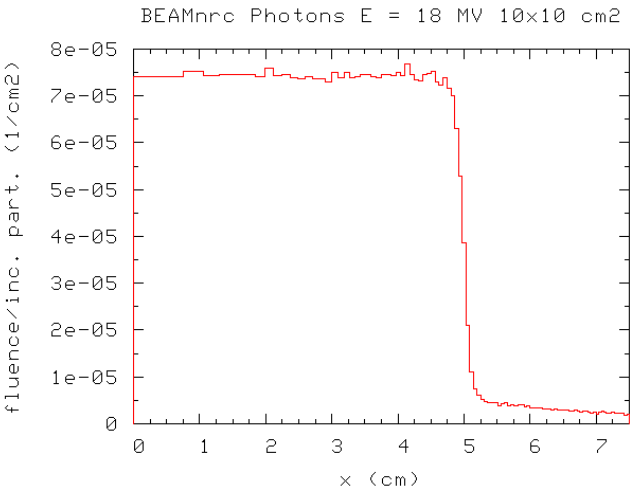
backbone program
written in Mortran3
a Fortran77 extension
language

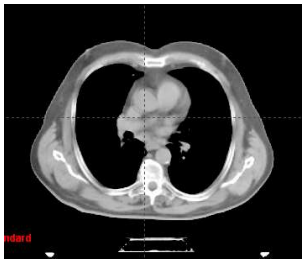


input file → BEAMnrc



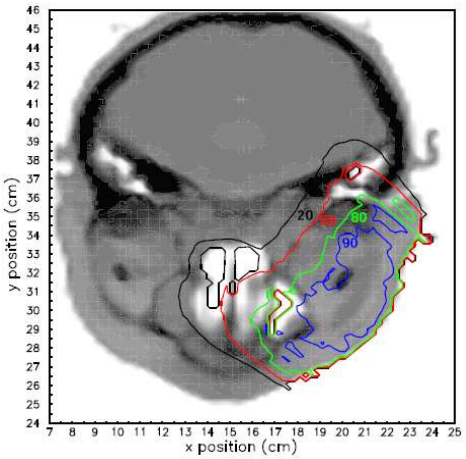
BEAMnrc → phase space file → beamdp





CT images set → ctcreate → DOSXYZ ← input file

DOSXYZ → Dose matrix

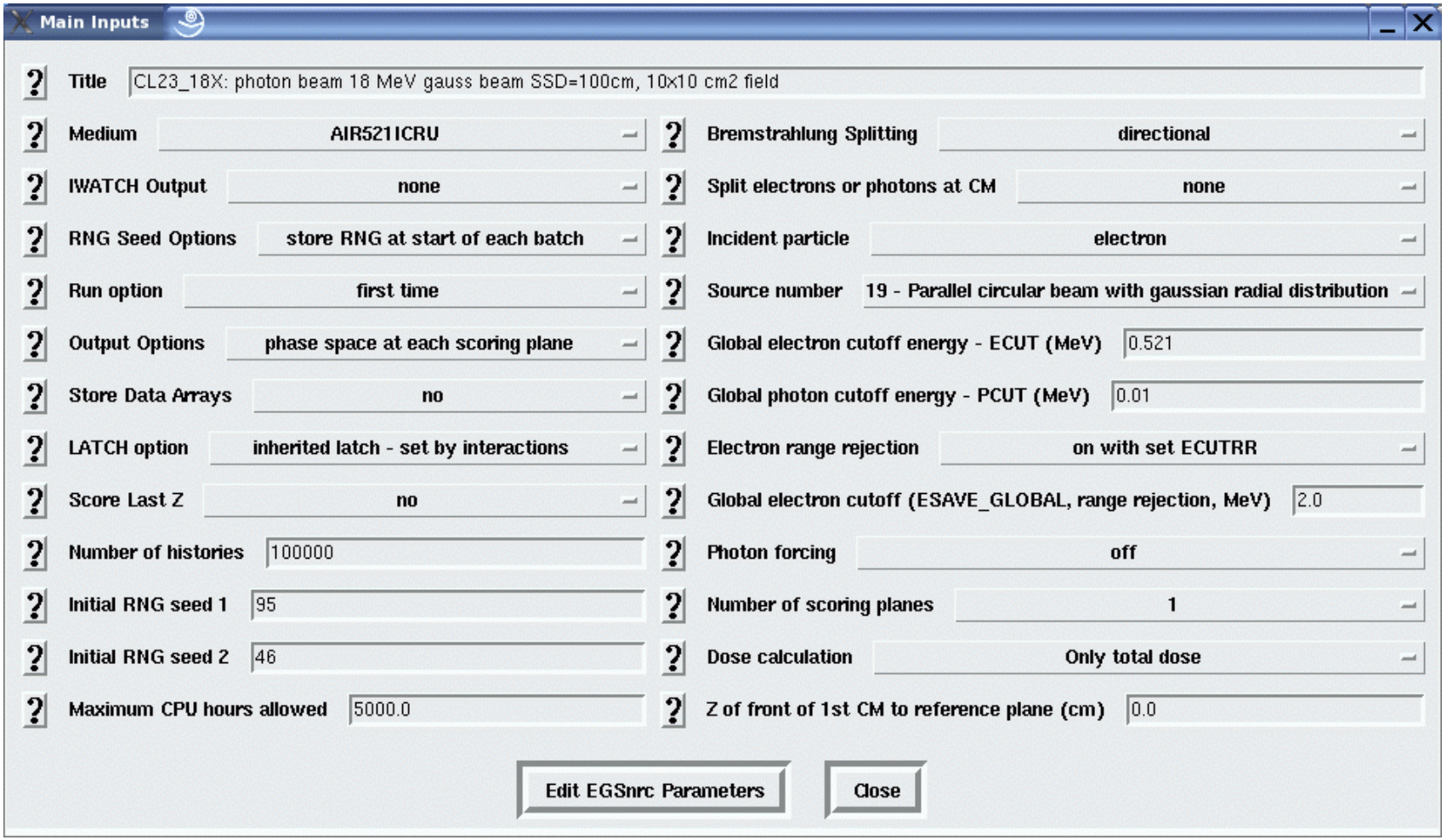


DOSXYZ ↔ DOSRZnrc
FLURZnrc
CAVRZnrc
SPRRZnrc
CAVSPHnrc
EDKnrc

interchangeable codes

BEAMnrc

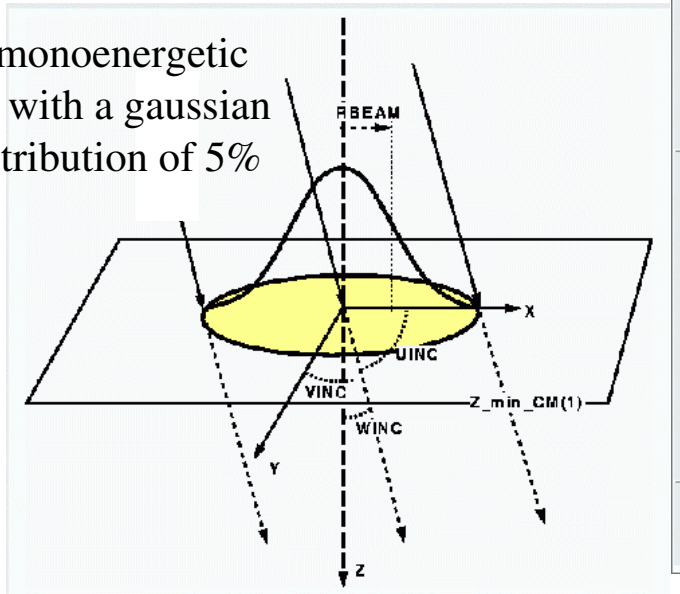
18 MV photon beam 10x10 cm^2 field
Head simulation Phase space scoring plane at SSD = 100 cm

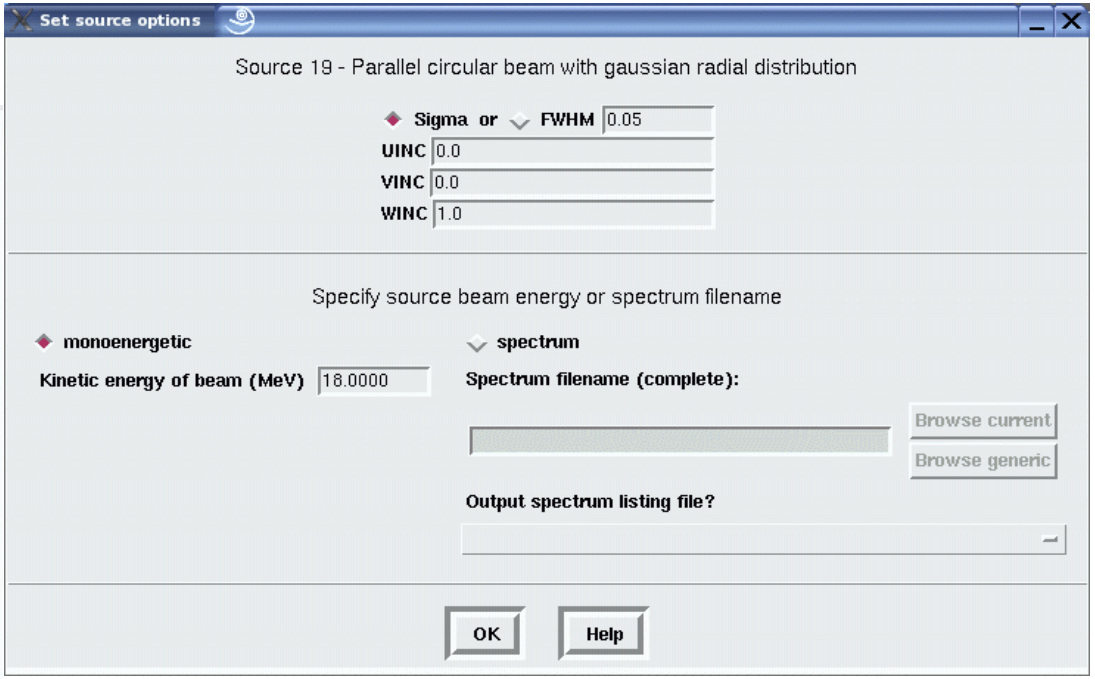


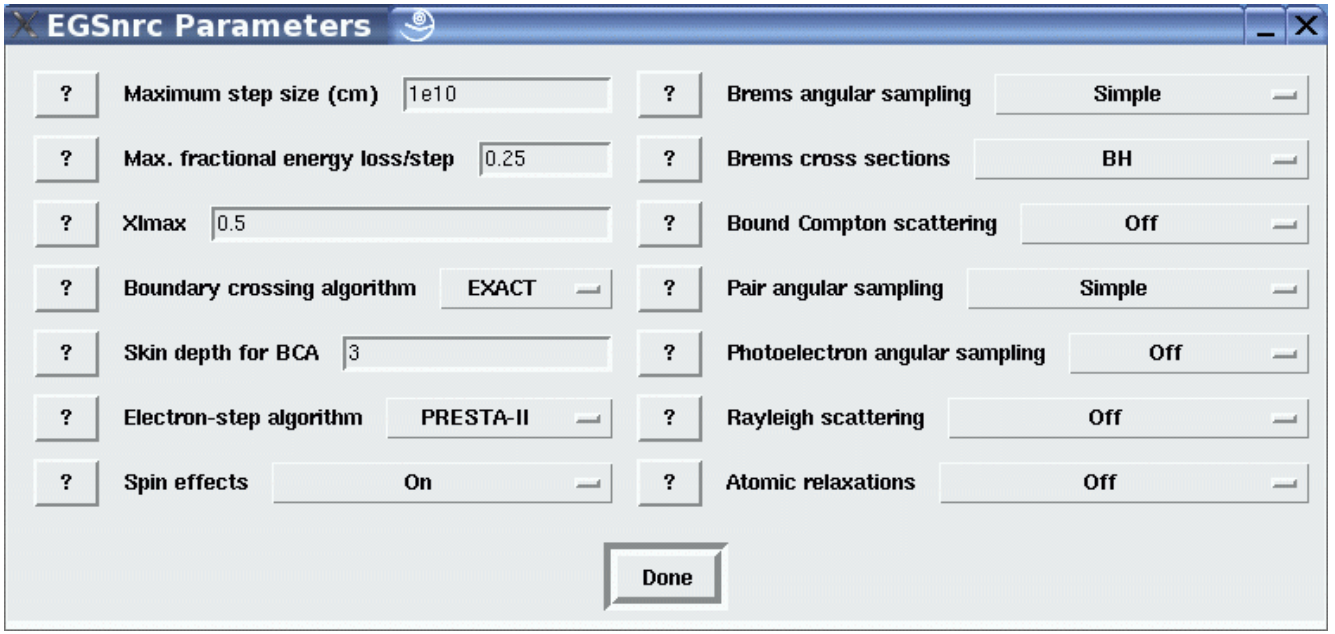
BEAMnrc

Source window

18 MeV monoenergetic electrons with a gaussian radial distribution of 5% FWHM





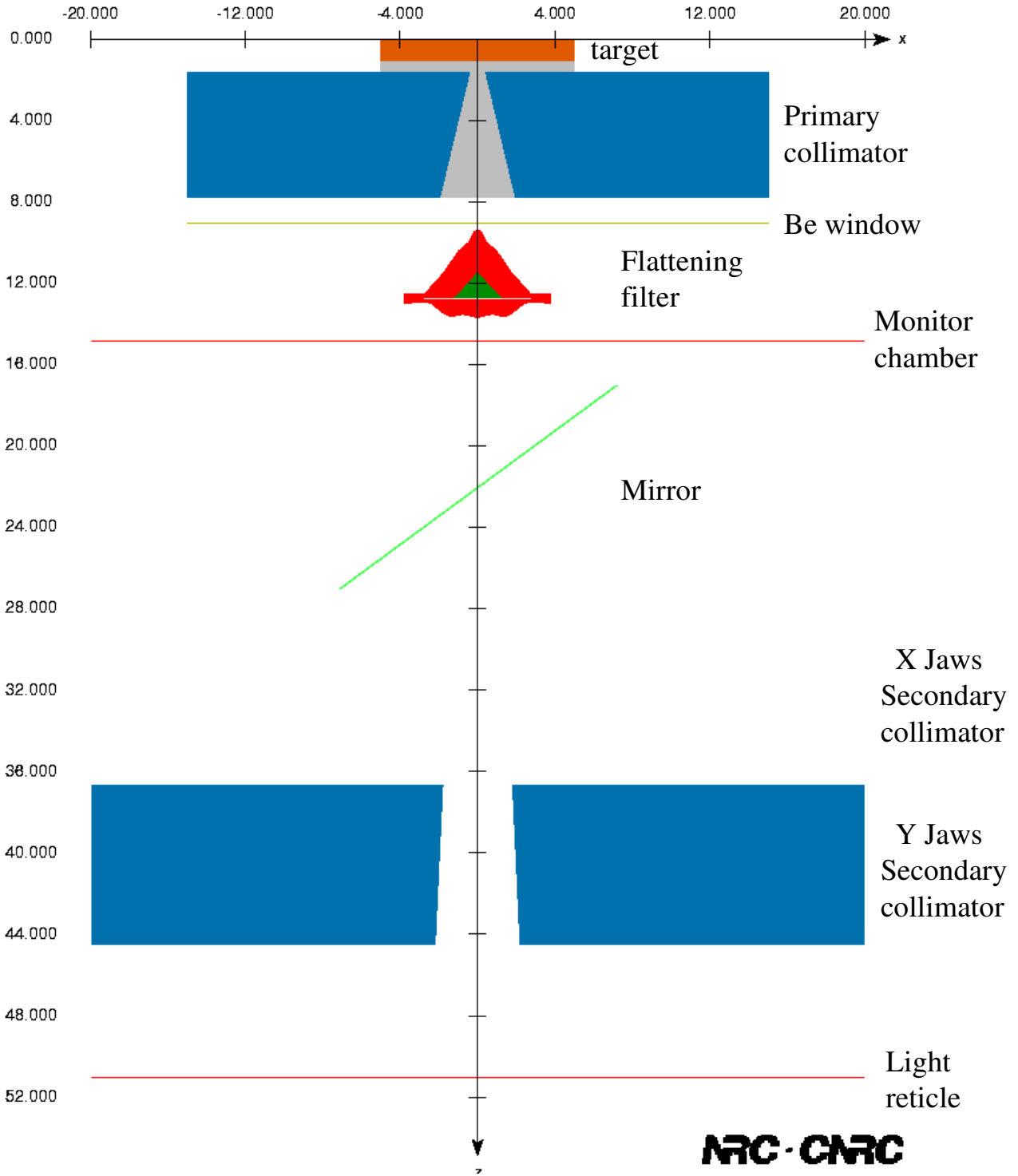


EGSnrc window

BCA: Exact
Skin depth: 3 mfp
Electron step algorithm: Presta II

BEAMnrc

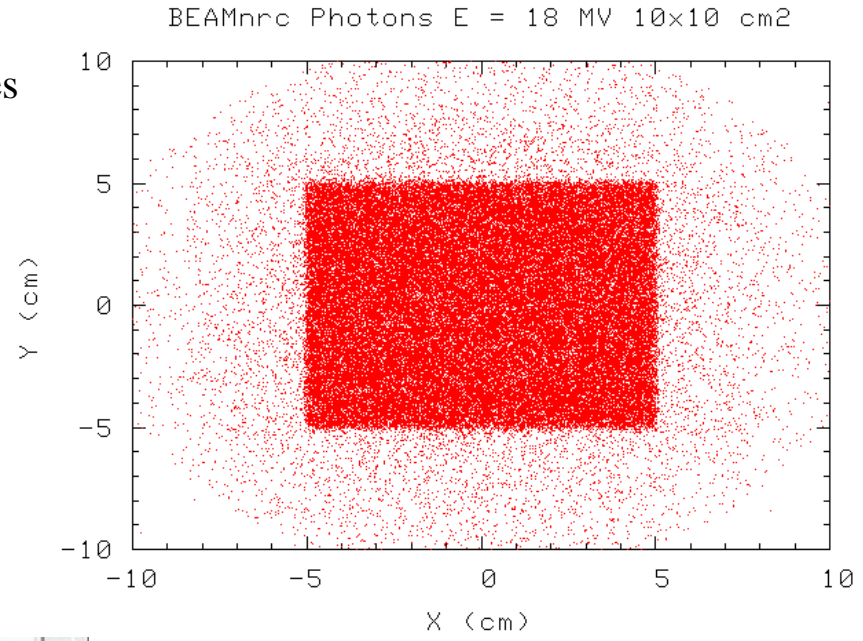
Preview of a
18 MV accelerator



Scoring plane
at SSD = 100 cm

Beam data processor (beamdp)

X-Y scatter plot of particles from phase space file



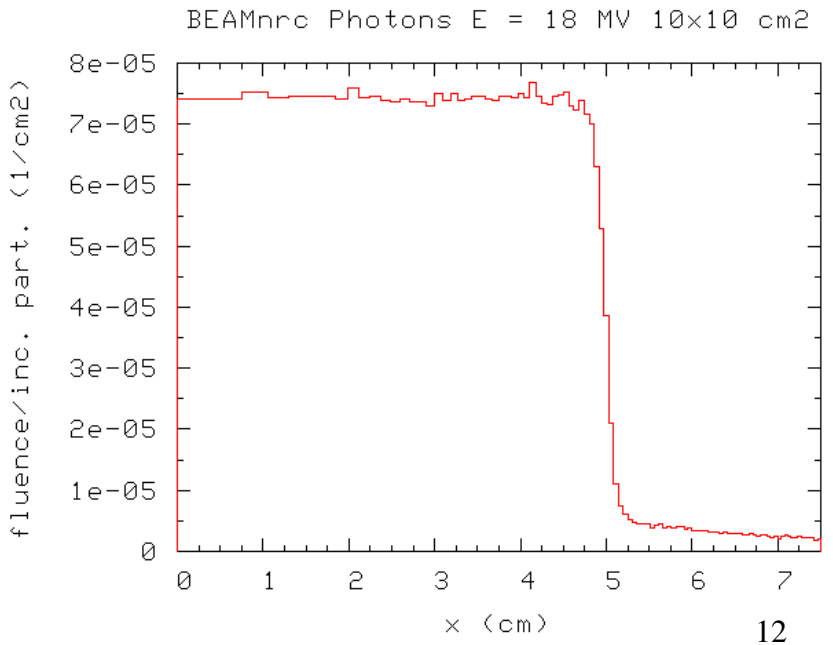
List phase space data

beamdp Output

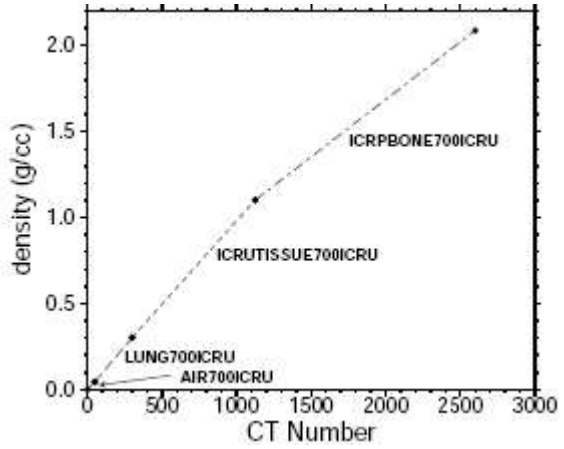
```
Name of file containing phase space data (with ext., < A100):
 File name input is:/home/hase/EGSnrc/user/BEAM_CL23a/be18_10x10_cl23a.egsphsp1


First, try to open it as a MODE0 file

          TOTAL NUMBER OF PARTICLES IN FILE:       402241
                    TOTAL NUMBER OF PHOTONS:       401375
           THE REST ARE ELECTRONS/POSITRONS.

     MAXIMUM KINETIC ENERGY OF THE PARTICLES:       17.978 MeV
     MINIMUM KINETIC ENERGY OF THE ELECTRONS:        0.017 MeV
# OF INCIDENT PARTICLES FROM ORIGINAL SOURCE:     100000.0

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

 2.279   0   1.064  -3.148  0.011 -0.031  0.999 2.000E-03  00000 00000000000000000000010
 1.822   0  -2.431  -3.089 -0.024 -0.030  0.999 2.000E-03  00000 00000000000000000000010
 9.090   0   3.558  -1.972  0.035 -0.019  0.999 2.000E-03  00000 00000000000000000000010
 2.741   0  -3.003  -0.262 -0.032 -0.001  0.999 2.000E-03  00000 00000000000000000000010
 1.566   0   3.933   0.688  0.039  0.008  0.999 2.000E-03  00000 00000000000000000000010
 4.054   0   3.840  -4.618  0.038 -0.045  0.998 2.000E-03  00000 00000000000000000000010
 4.626   0   2.374   3.352  0.023  0.034  0.999 2.000E-03  00000 00000000000000000000010
 6.606   0  -6.437   3.184 -0.078  0.052  0.996 2.000E-03  00000 00000000000000000000010
```

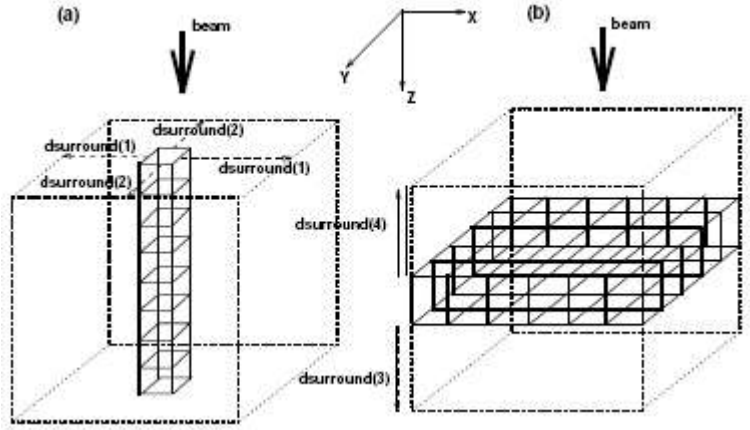
Close

Fluence vs. position from phase space file



DOSXYZnrc





Inputs

Title: DD curve for 18MV 10x10 from CL23a.egsphsp1. Scoring plane at z=100cm

Phantom definition

If you are using source 2 or 4, you must define the materials in the phantom here first before defining the source.

Define phantom using ... — non-CT data input / phantom created from CT data

Global electron cutoff energy - ECUT (MeV): 0.52

Global photon cutoff energy - PCUT (MeV): 0.01

Print summary of highest 20 doses: no

Source parameters

Incident particle: all

Source type: 2 - Full phase-space source file

Simulation parameters

Number of histories: 1000000

IWATCH Output: none

Maximum CPU time (hours): 5000

RNG seed 1: 33

RNG seed 2: 97

Incident beam size (source 2, 4 or 8): 15.0

Run option: first time

Thickness of region outside phantom is: non-uniform

Medium of region outside phantom: H2O521ICRU

Output restart data: never

Range rejection: off

ESAVE: range rejection done only below this energy (MeV)

Photon splitting number: 0

times to recyle each particle in phase space source: 0

Run job in parallel: no

Edit EGSnrc Parameters | Close

Set source options

Source 2 - Full phase-space source file

x-coordinate of the isocenter: 1

y-coordinate of the isocenter: 1

z-coordinate of the isocenter: 0

Theta (degrees): 180

Phi (degrees): 0

Distance from source to isocenter (cm): 0

Collimator angle (degrees): 0

DBS used to generate source

DBS splitting field radius (cm): 11

SSD of splitting field (cm): 100

Z where source scored (cm): 100

Phase space beam input (with no LATCH filter)

Phase space beam input + dose component (with LATCH filter)

File containing phase space data: /home/hase/egsnrc/user/BEAM_CL23a/be18_10x

Browse current directory

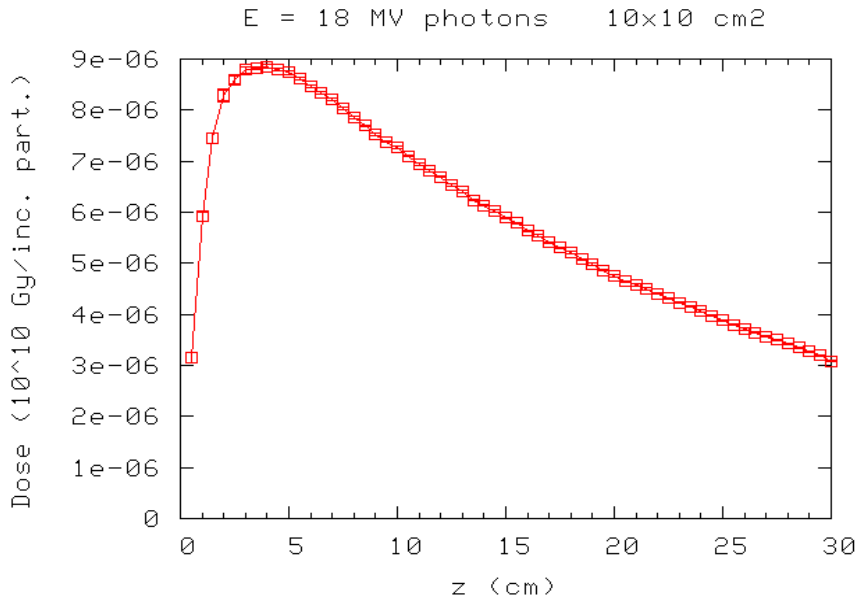
Phase space data redistribution: redistribute

Phase space file format: no ZLAST

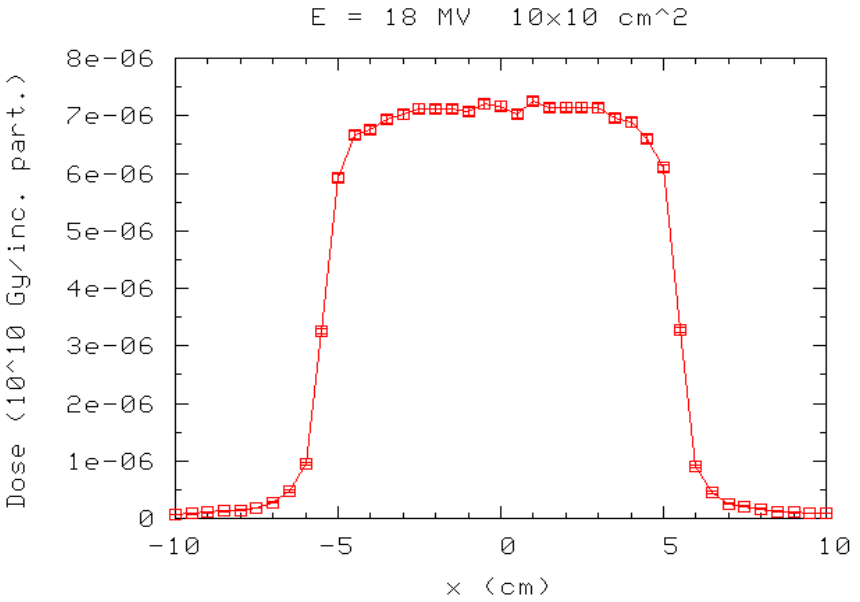
LATCH Bit filter

OK | Help

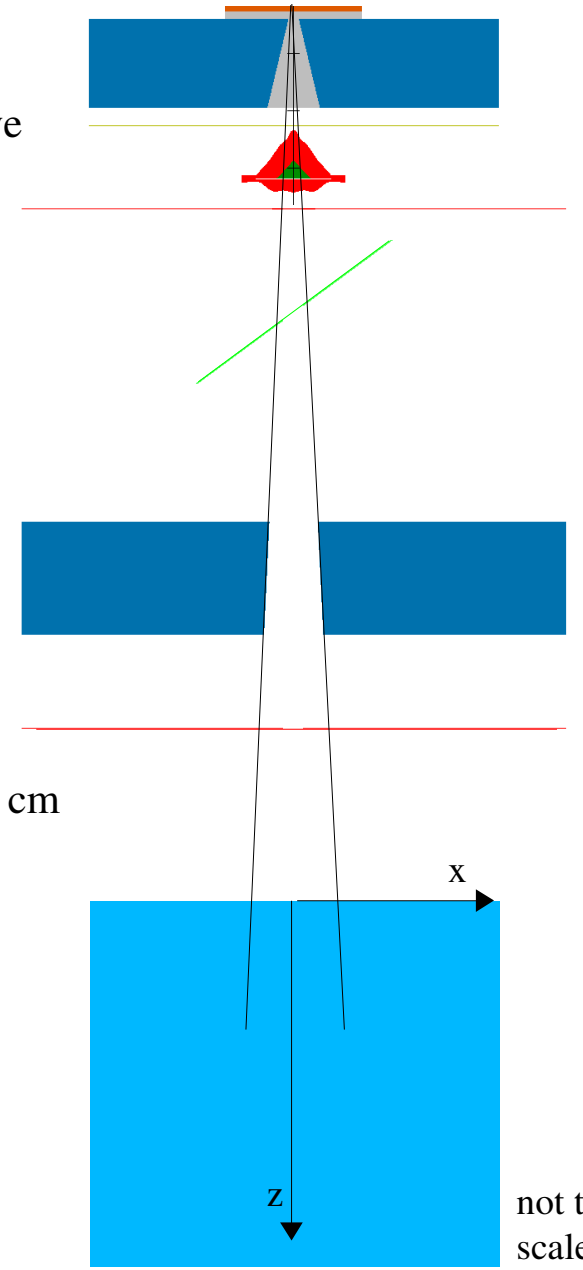
BEAMnrc results



depth dose curve in water



profile at z = 10 cm in water



not to scale

Geant 4

Run

initialization, termination, control of histories

G4RunManager::
DoEventLoop()

classes: G4RunManager (managing class)
G4UserRunAction (user control class)
G4Run

Event

simulation of one history

G4EventManager::
ProcessOneEvent()

classes: G4EventManager (managing class)
G4UserEventAction (user control class)
G4Event

Track

intermediate level between event and step

G4TrackingManager::
ProcessOneTrack()

classes: G4TrackingManager (managing class)
G4UserTrackingAction (user control class)
G4Track

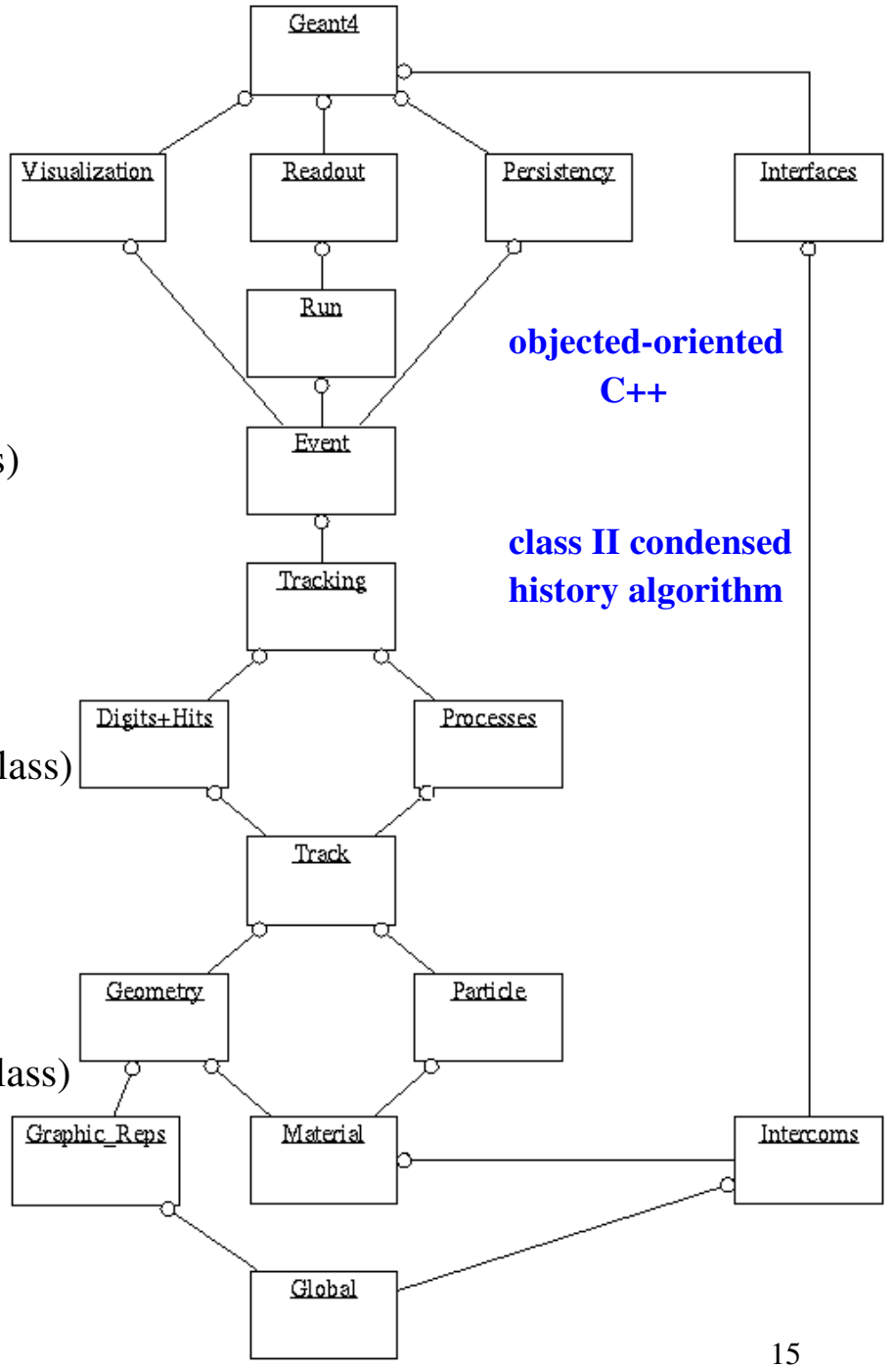
Step

advancing one step

G4SteppingManager::
Stepping()

classes: G4SteppingManager (managing class)
G4UserSteppingAction (user control class)
G4Step

G4Transportation
AlongStepDoIt
PostStepDoIt



objected-oriented
C++

class II condensed
history algorithm

Ref: Agostinelli, S. et al., GEANT4 – A simulation toolkit.
Nucl. Instr. and Meth. Phys. Res., **A506** (2003) 250 – 303.

Geant 4 range cut

For kinetic energies between 0.5 -1 MeV the step size is limited by the requirement that the stopping power should not decrease by more than 20%. This guarantees that cross sections vary little over a step. For low energies this gives too short step sizes. Therefore, a cut in range is introduced.

The production threshold of secondaries in Geant 4 is specified in terms of distance for each particle. These ranges are internally converted to energies for every geometric volume.

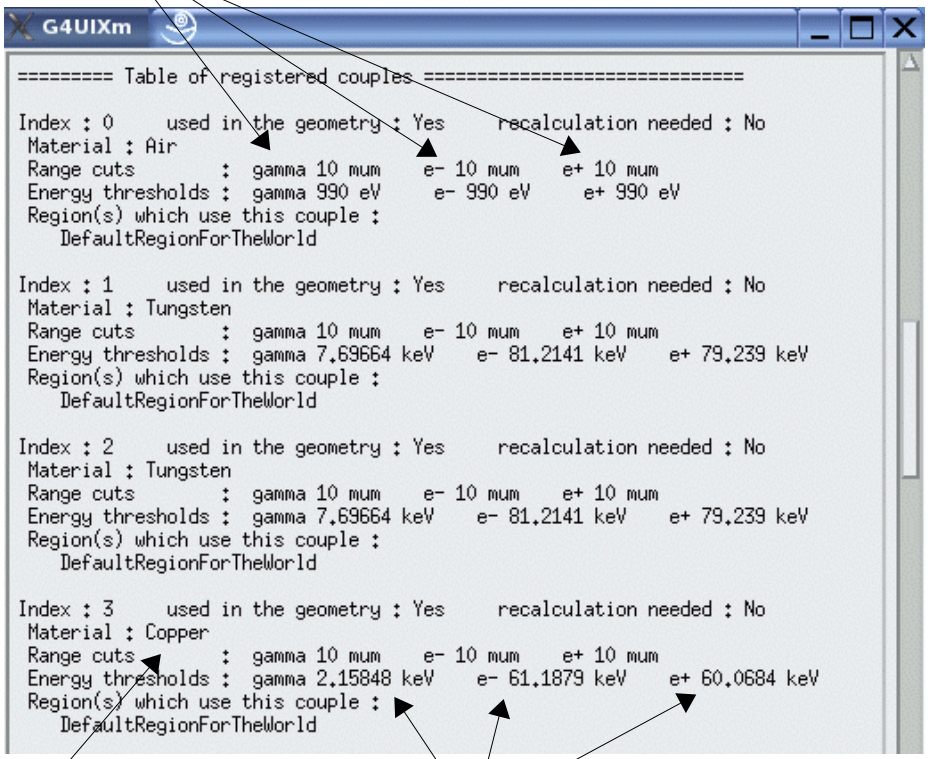
Secondary particles that cannot travel longer than their respective threshold ranges are not generated, but accounted for using the continuous slow down approximation (CSDA).

The minimum threshold energy corresponds to
1 keV for the *Standard model*
0.25 keV for the *Low-energy model*

Alternatively, different thresholds can be defined in different regions, G4Region->SetProductionCut . and maximum step size restrictions set with SetUserLimits.

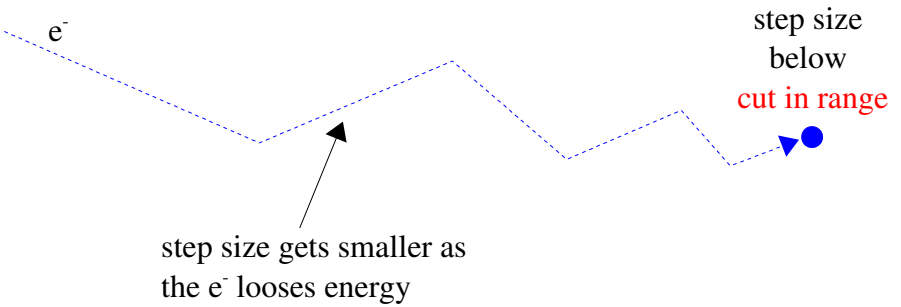
default cut value = 10 µm

DumpCutValuesTable()

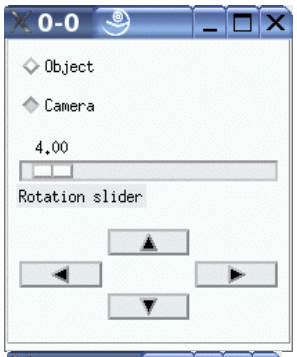


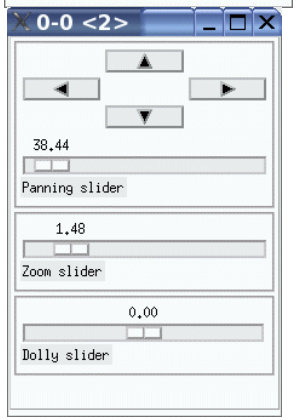
Medium

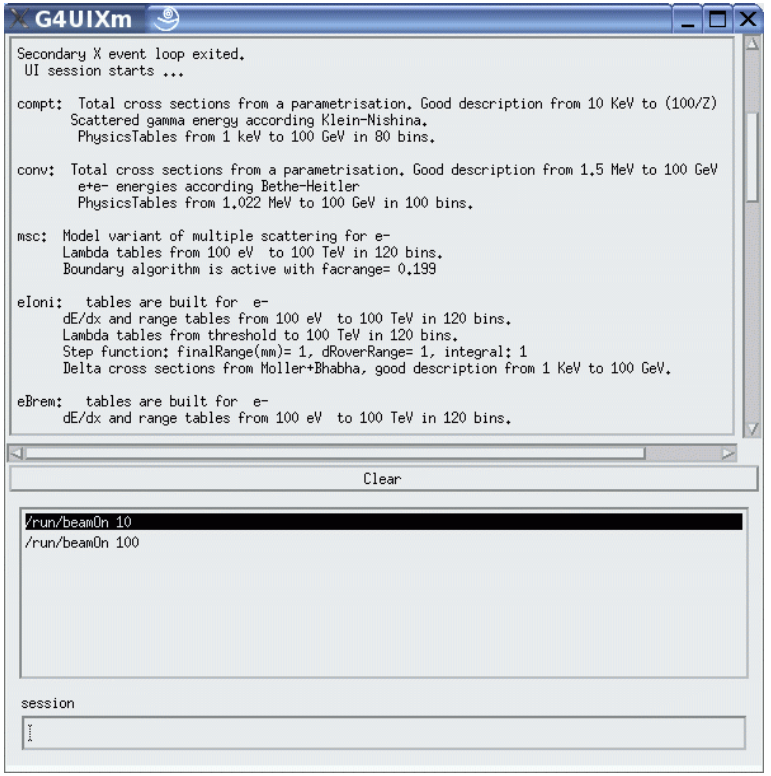
Energy production thresholds

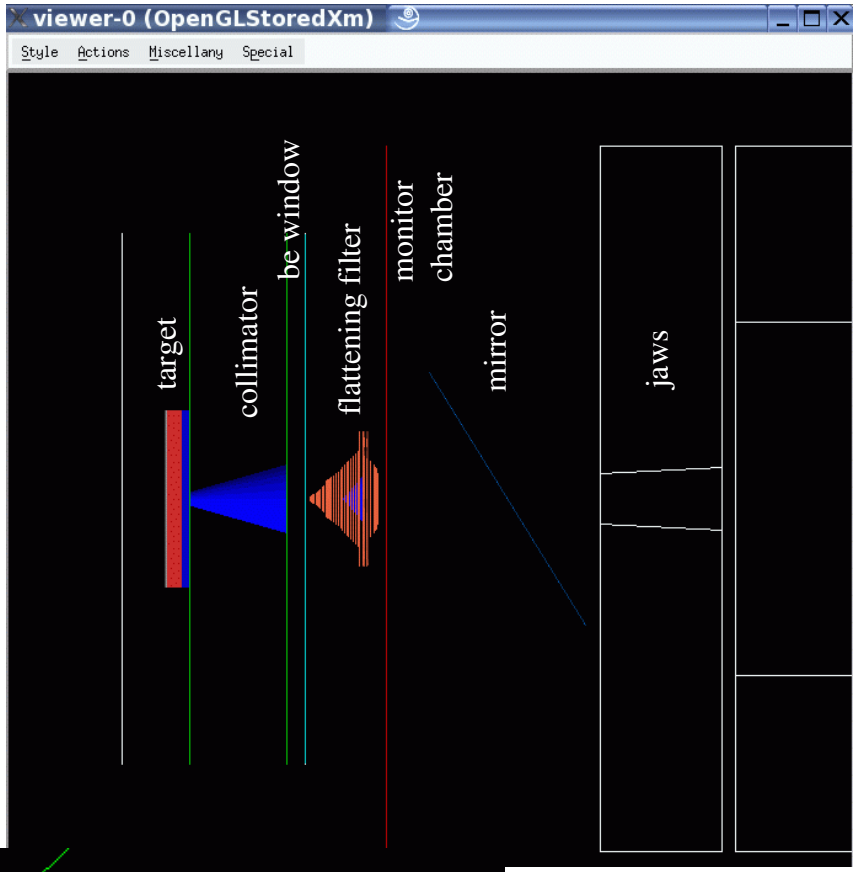


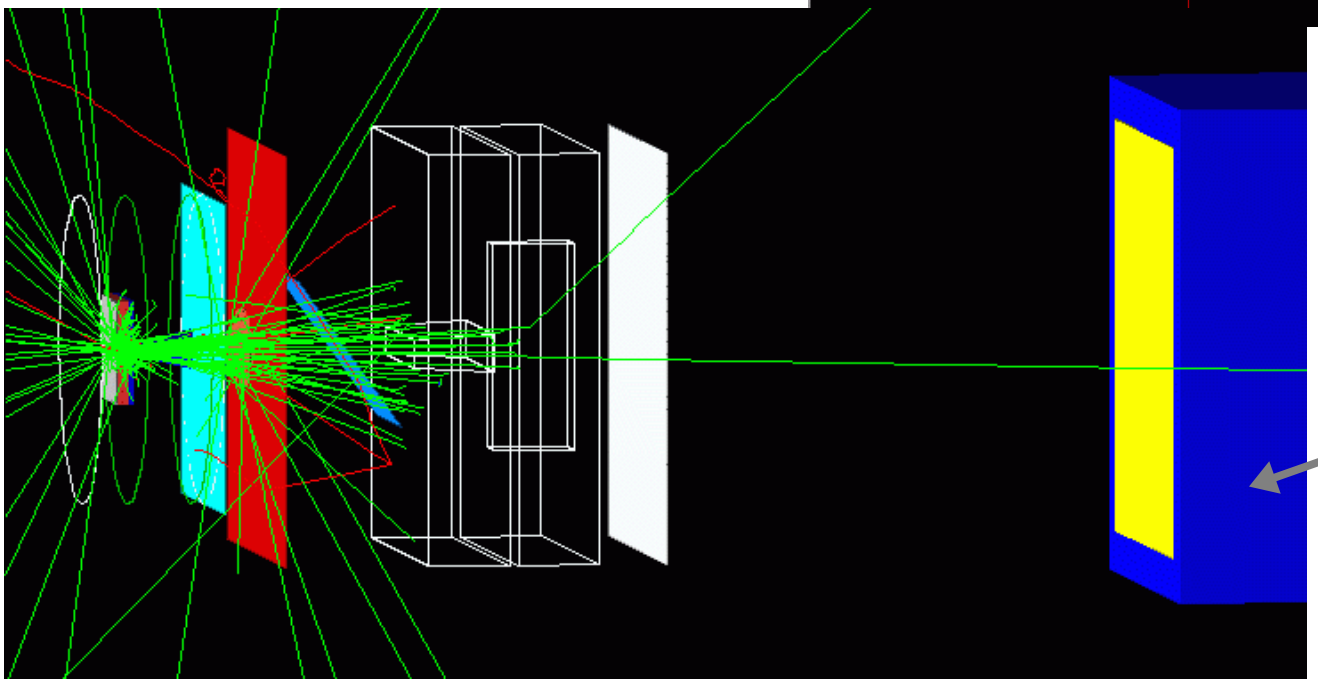
Geant 4









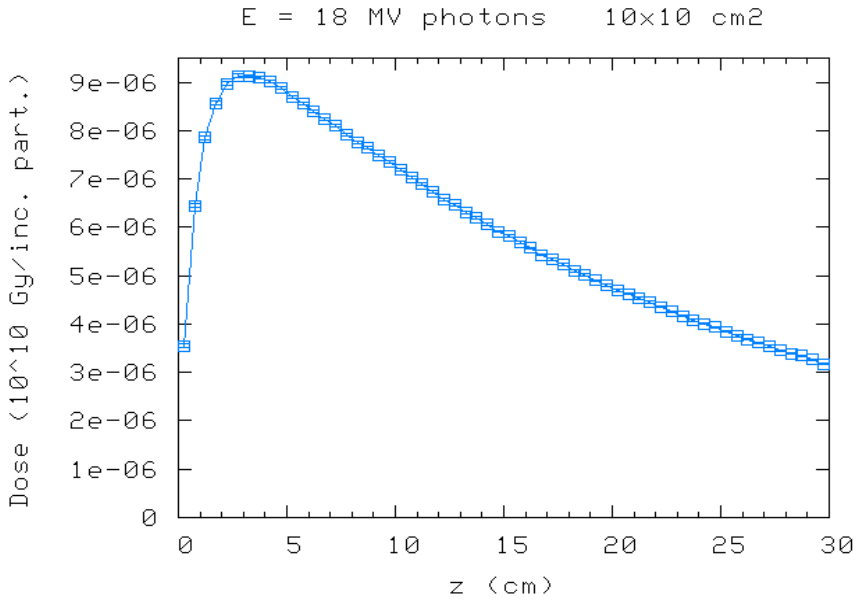


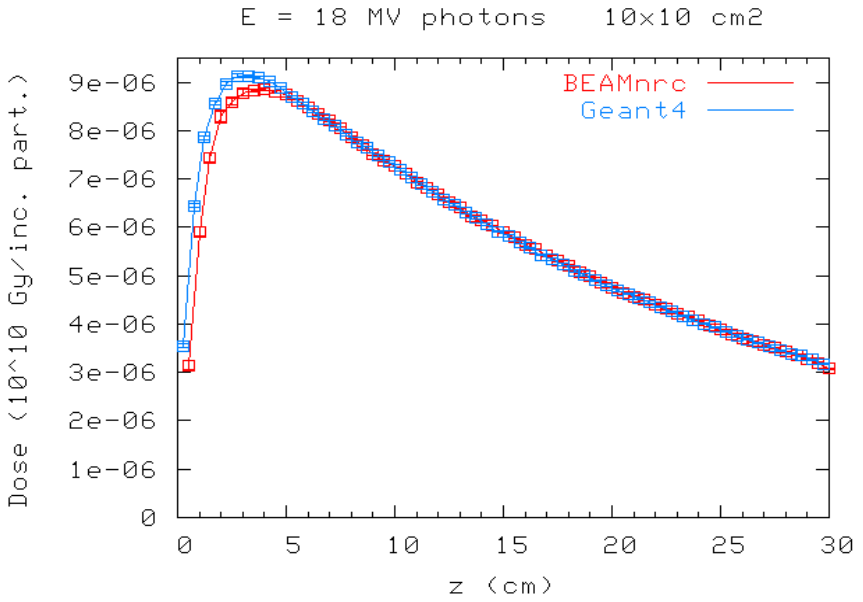
View of a 18 MV accelerator

dose deposited in water phantom computed with DOSXYZnrc

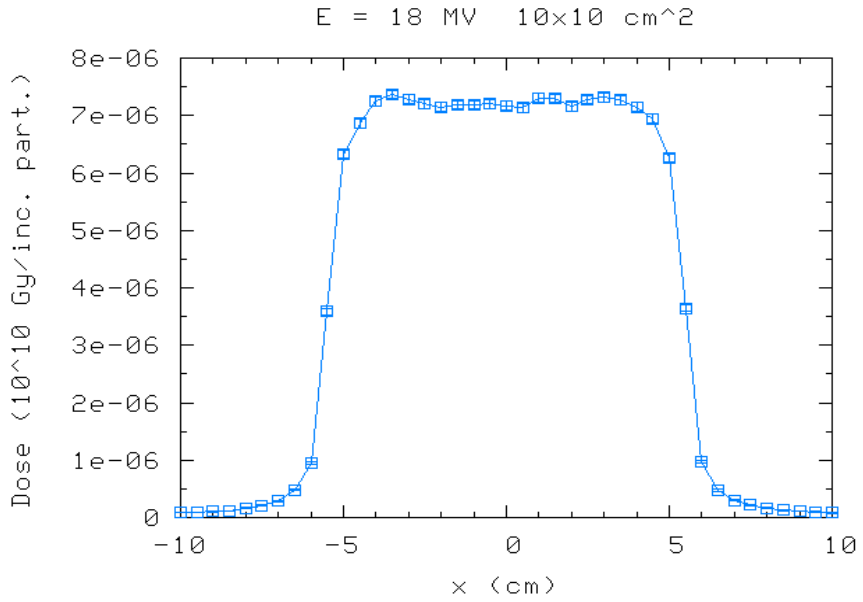
Geant 4 + DOSXYZnrc

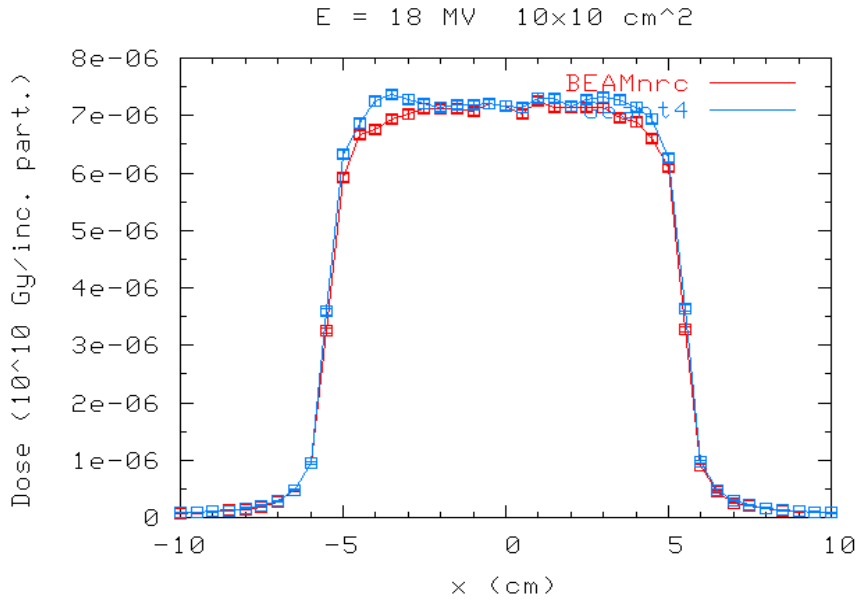
depth dose curves in water





profiles at z = 10 cm in water





Geant 4 conclusions

Geant 4 has powerful geometry construction capabilities and numerous interaction types. The user has a high level of control over the particle simulation process.

The performance of Geant 4 has not been optimized sufficiently, and it is an order of magnitude slower than EGSnrc.

The appropriate selection of physics processes and transport parameters are particularly important for optimum efficiency and accuracy.

The electron transport mechanics in Geant 4 appears inadequate for clinical applications where an accuracy of 2% is required. A suitable user-imposed step limitation is necessary.

Geant 4 is appropriate for radiotherapy applications where electron transport is not critical.

Ref: Poon, E. and F. Verhaegen, Accuracy of the photon and electron physics in GEANT4 for radiotherapy applications. *Med. Phys.*, **32** (2005) 1696 – 1711.

Variance reduction techniques

The efficiency of MC simulations can be increased by
a) reducing the variance
b) reducing the CPU time per particle simulated

Techniques leading to efficiency increase, although not always associated with variance reduction, are called variance reduction techniques.

Variance reduction basic idea:

expected mean μ is not changed by variance reduction $\longrightarrow$ $$\mu = \int x\, f(x)\, dx = \int x \left[\frac{f(x)}{g(x)}\right] g(x)\, dx$$

variance σ^2 is changed due to altered sampling scheme $\longrightarrow$ $$\sigma^2 = \int (x-\mu)^2 f(x)\, dx = \int x^2 f(x)\, dx - \mu^2 = \int x \left[x \frac{f(x)}{g(x)}\right]^2 g(x)\, dx - \mu^2$$

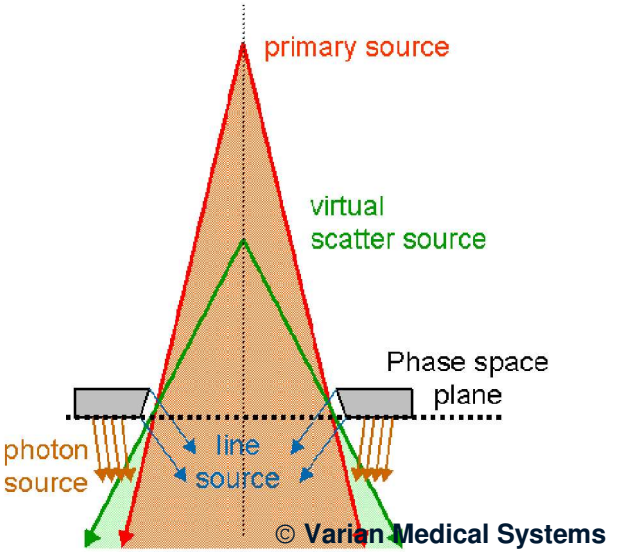
Goal: choose $g(x)$ such that variance is reduced.

Variance reduction techniques:
time and energy cutoffs
geometry splitting and roulette
weight windows
exponential transform
forced interactions
general source biasing
secondary particle biasing
range rejection

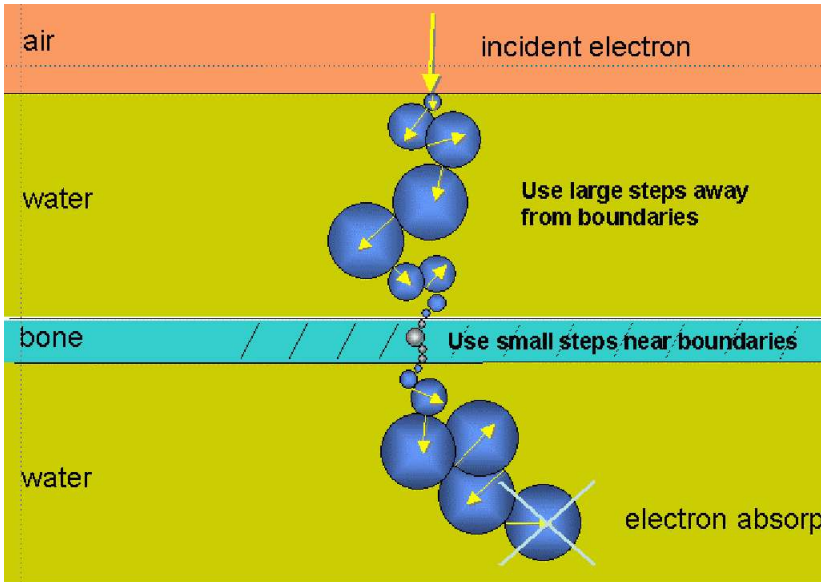
eMC

Beam model (Initial Phase Space Model)[1]

Is adjusted by measurements (PDD's and Profiles). Pre-calculated results are used as an input for the transport model.



[1] Janssen, J., E. Korevaar, L. van Battum, P. Storchi, and H. Huizenga, A model to determine the initial phase space of a clinical electron beam from measured beam data. *Phys. Med. Biol.*, **46** (2001) 269-286.



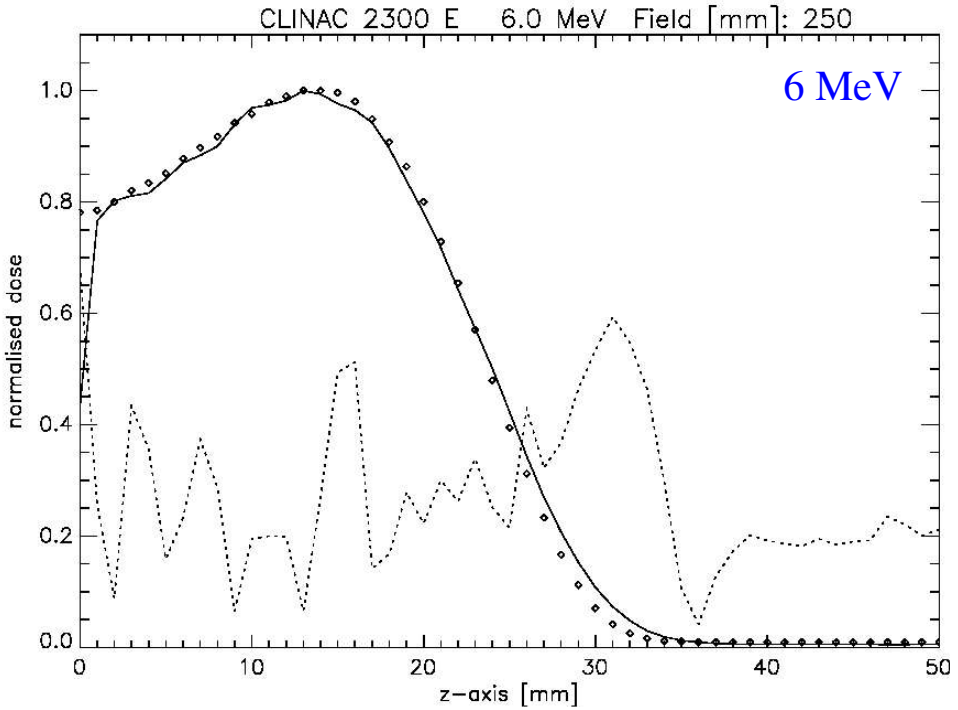
Transport model (Macro Monte Carlo MMC)[2]

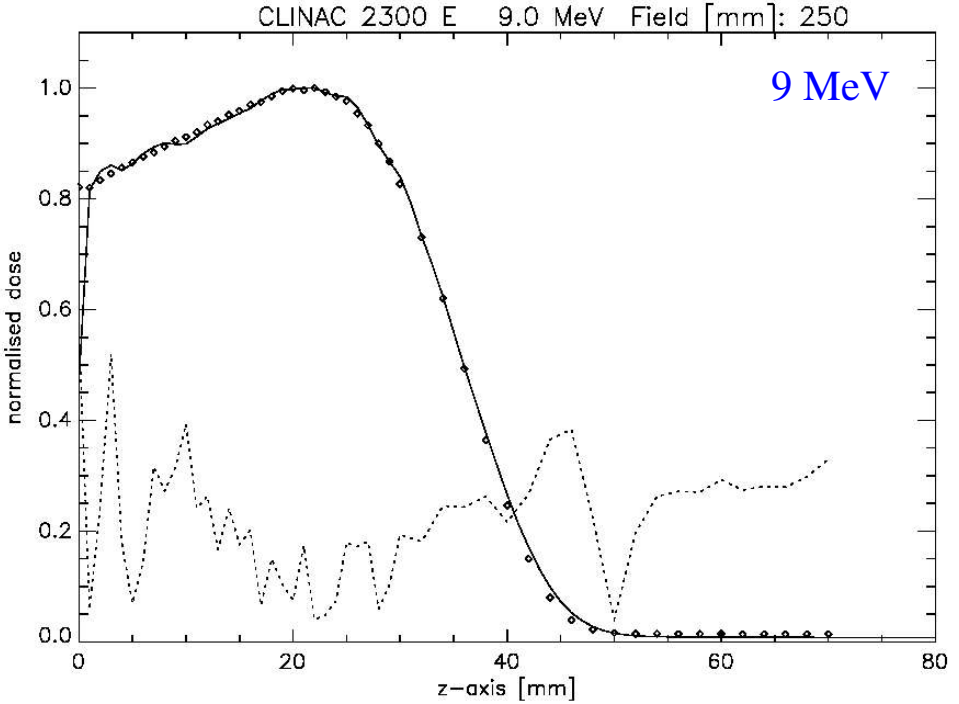
The local geometry is pre-simulated for spheres with different materials and incident energies and the resulting PDF's (stored in a database) are used for transporting the electrons in macroscopic steps through the absorber.

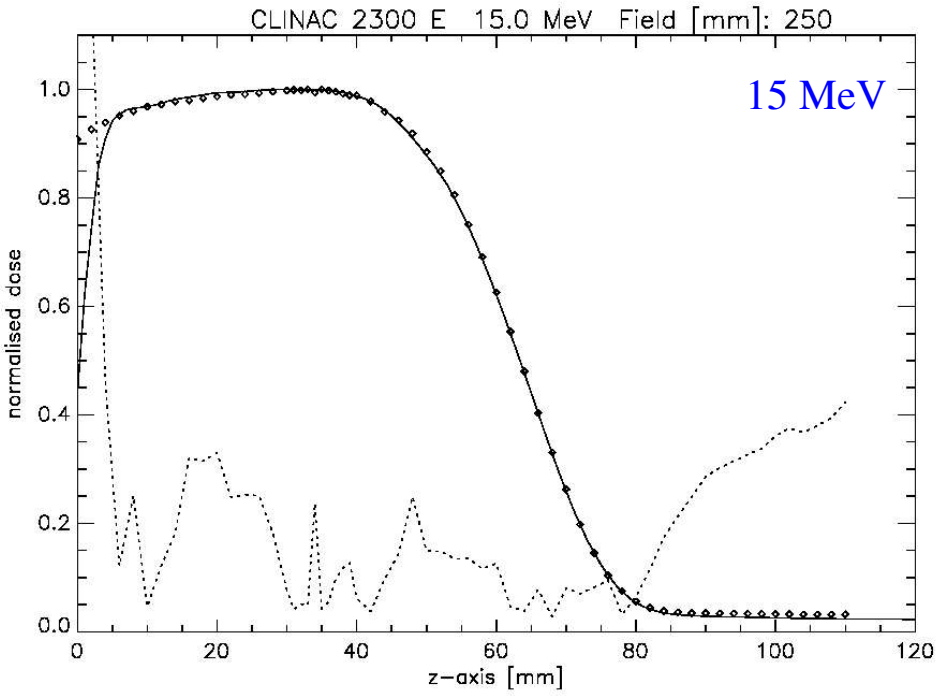
[2] Neuenschwander, H. and E. Born, A macro Monte Carlo method for electron beam dose calculations. *Phys. Med. Biol.*, **37** (1992) 107 – 105.
Neuenschwander H., T. R. Mackie, P. J. Reckwerdt, MMC-a high performance Monte Carlo code for electron beam treatment planning. *Phys. Med. Biol.*, **40** (1995) 543 – 574.

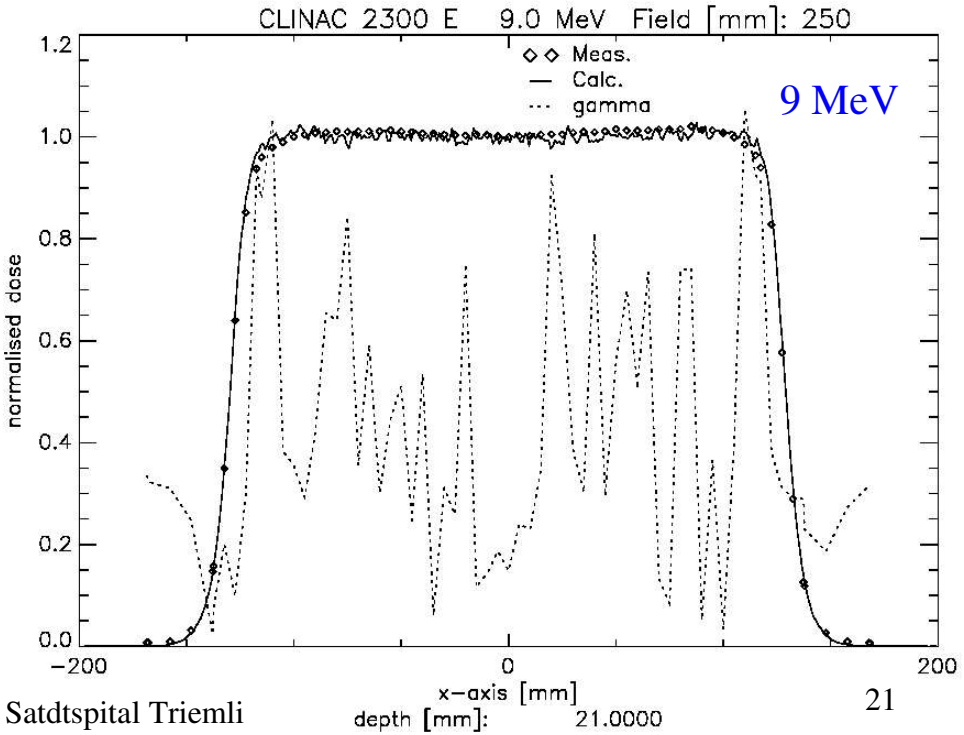
Courtesy: P. Pemler, Satdtspital Triemli

eMC Results



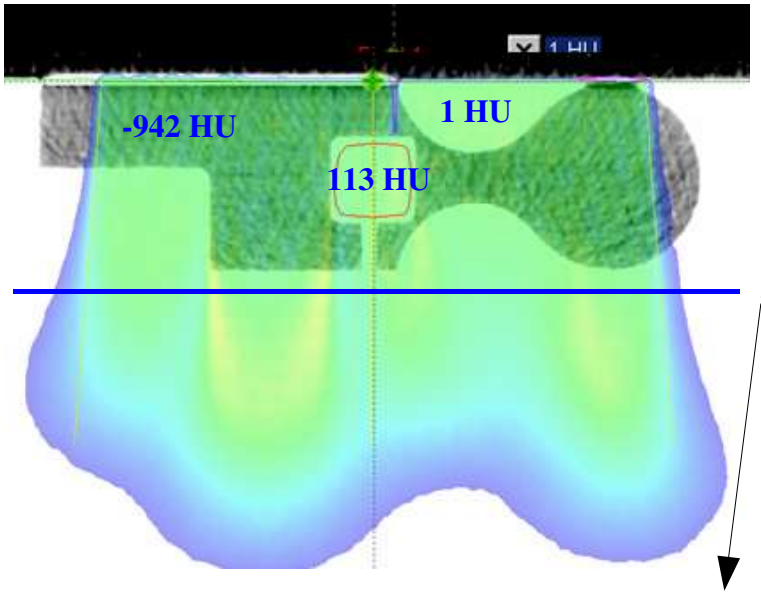


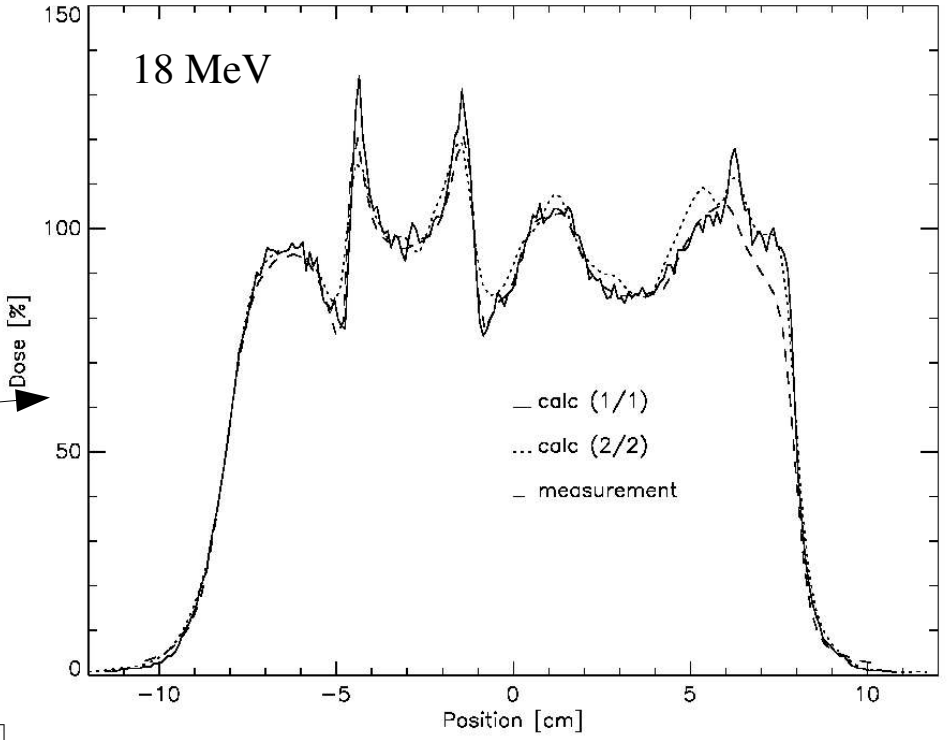


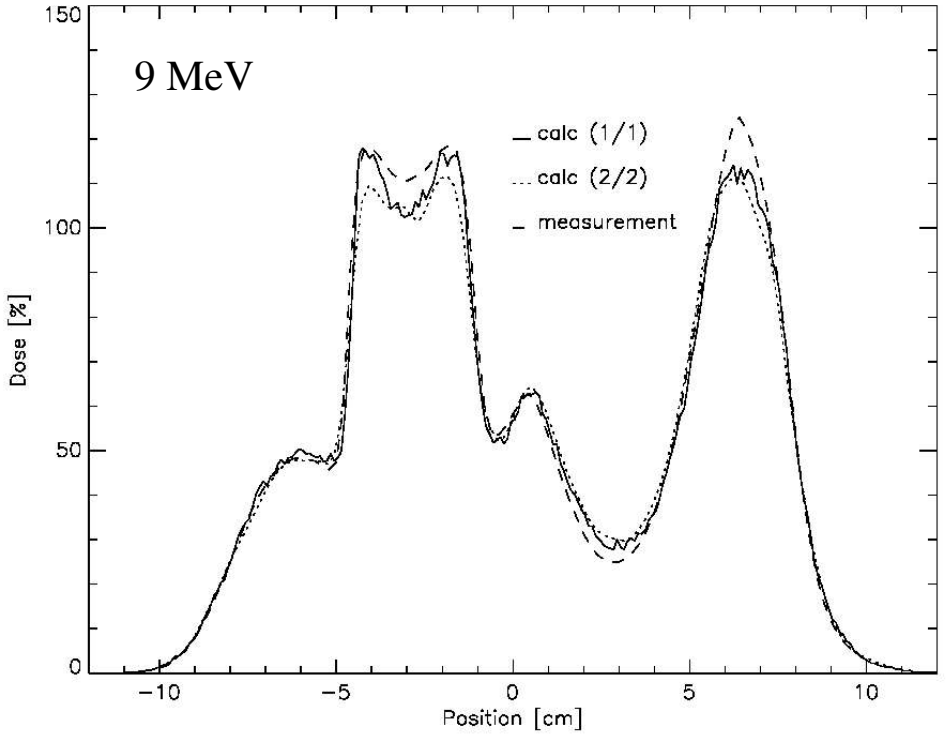


Courtesy: P. Pemler, Satdtspital Triemli

eMC profiles in a inhomogeneity phantom







Measurements:

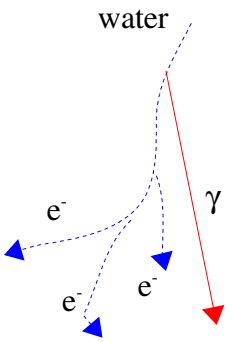
Diamond detector
Standard imaging
A 10x6, A10 – A25

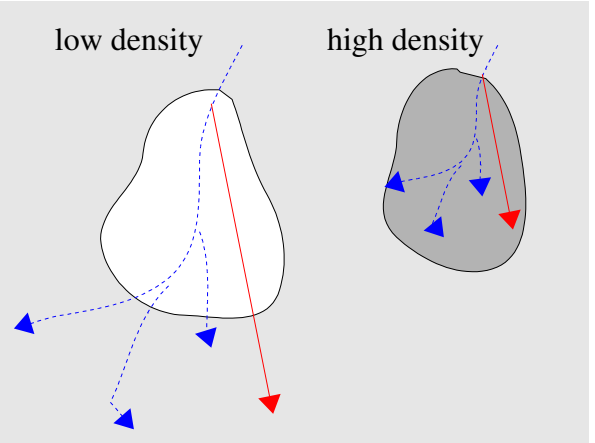
Courtesy: P. Pemler, Satdtspital Triemli

Voxel Monte Carlo (VMC)

Basic idea: human tissue is composed of low Z materials. Therefore, interactions and cross sections are scalable using functions $f_i(\rho)$ to that of **water**,

$$\mu_i(E,\rho)=\mu_i^w(E)\,f_i(\rho)\frac{\rho}{\rho^w}$$





The values of $f_i(\rho)$ for photoelectric effect, Compton, pair production, elastic and inelastic e$^-$ scattering are obtained through appropriate parametrizations.

This procedure represents an efficiency improvement in inhomogeneous media, since the same particle history can be used in regions of different densities. The step sizes and scattering angles are scaled according to the tissue densities.

The e$^-$ transport through boundary crossings is also speed up. Conventional e$^-$ transport algorithms are CPU demanding at the interfaces where multiple mathematical operations are performed.

Another advantage is that the exact chemical composition of the tissues is not required, only their densities.

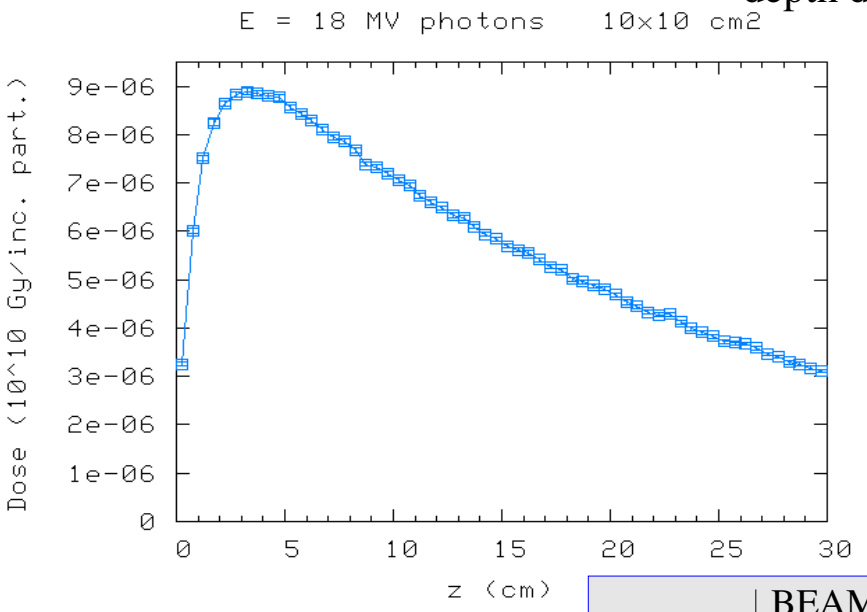
Refs: Kawrakow I., et al., 3D electron dose calculation using a Voxel based Monte Carlo algorithm (VMC). *Med. Phys.*, **23** (1996) 445 – 447.
Fippel M., Fast Monte Carlo dose calculation for photon beams based on the VMC electron algorithm. *Med. Phys.*, **26** (1999) 1466 – 1475.
Kawrakow I. and M. Fippel, Investigation of variance reduction techniques for Monte Carlo photon dose calculation using XVMC. *Phys. Med. Biol.*, **45** (2000) 2163 – 2183.

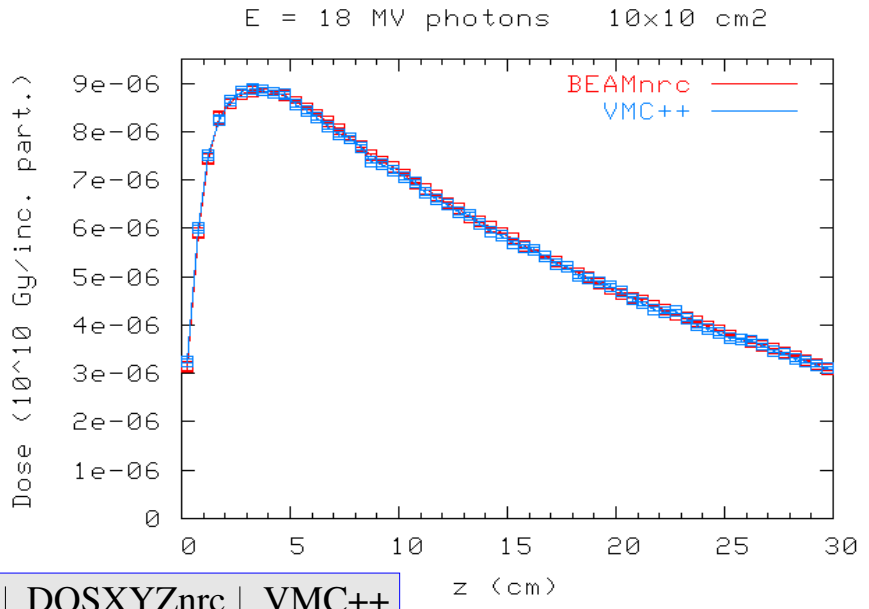
Voxel Monte Carlo (VMC)

```
hase@ams15:~/vmc++/runs> vmcpp.exe -i cl21ex_18_10x10mig
Preparing simulation data...
Read zo = 0
Read nimp = 7
Read importances
 finished layer 0
 ...
  ne_split = 120
  np_split = 15
  max. imp = 512
  Nsplit   = 4096
In VMC_PhotonLinacSource::~VMC_PhotonLinacSource: ip = 10000
 Source has Emax = 18  Ep = 3.6
DE_MC_Parameter::init_steps(): alpha = 0.148163  beta = 0.366615
================================================
                Monte Carlo Parameter
================================================
 Delta particle production threshold    :   0.521 MeV
 Bremsstrahlung production threshold:   0.01 MeV
 Min. electron transport energy         :   0.521 MeV
 Min. photon transport energy           :   0.05 MeV
 Local track-end energy deposition      :   0
 Cut-off energy for KERMA approx.  :   1 MeV
 Bremsstrahlung transport mode          :   2
 CSDA approximation                     :   0
 Fractional energy loss/step at Ep      :   25%
 Max. 1st elastic moment per step       :   0.5
 Max. acceptable energy loss/step       :   1e+10 MeV
 Min. acceptable energy loss/step       :   0.521 MeV
 alpha and beta                         :   0.148163  0.366615
 Fano calculation                       :   0
 Exact Compton                          :   1
 Spin effects                           :   2
================================================
Will use 1 particles per set
OK, cpu time so far 0.76 seconds
Running simulation
+ Finished 2% of simulation, cpu time = 30.31
...
+ Finished 100% of simulation, cpu time = 1485.07
DE_ScoreDose::analyze: ncase = 397596 nbatch = 0 fluence = 397596
 using history-by-history statistics
============ DE_ScoreDose::analyze: ====================
 max dose is 9.18998e-06 in region 12688
 efficiencies normalized to 9.18998e-06
  cpu time: 1485.07
  average stat. errors and efficiencies:
     D > 20%: 0.47066%  eff = 30.3976 (33534 voxels)
     D > 50%: 0.541505%  eff = 22.964 (16851 voxels)
     D > 90%: 0.631947%  eff = 16.8613 (2637 voxels)
================================================

  Efficiency derived from average relative uncertainty
  for  D > 50%:  11.6111 1/s

================================================

Finished simulation, cpu time this run = 1485.07

VMC_PhotonLinacSource::run_info():
  incident electrons: 397597
  photons:    13303576, <E> = 4.34379
  electrons: 2377652, <E> = 3.46348
  positrons: 318772, <E> = 3.53708

vmc_putDose():
++storing dose scan 1 in file /cl21ex_18_10x10mig.prof0
++storing dose scan 2 in file /cl21ex_18_10x10mig.prof1
++storing dose scan 3 in file /cl21ex_18_10x10mig.prof2
done

In VMC_PhotonLinacSource::~VMC_PhotonLinacSource: ip = 10000
```

Voxel Monte Carlo (VMC)

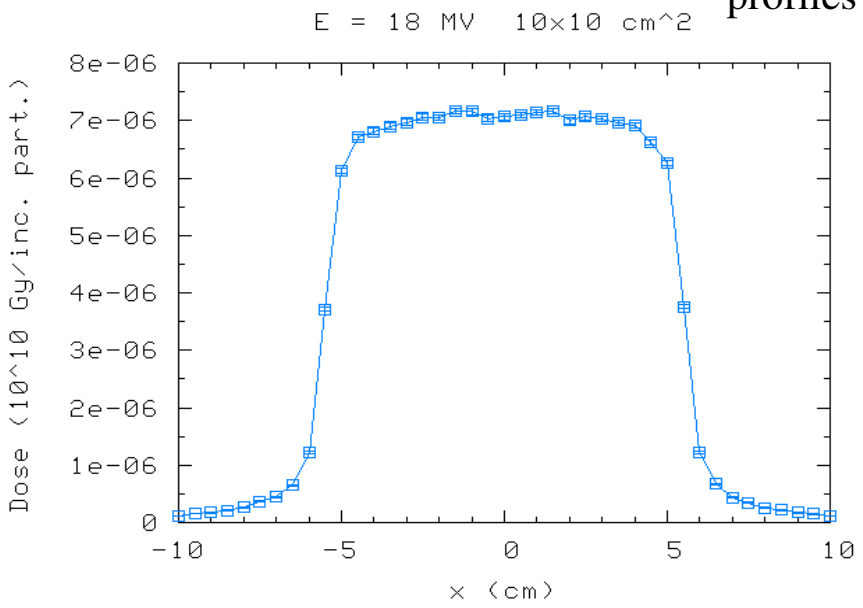
depth dose curves in water

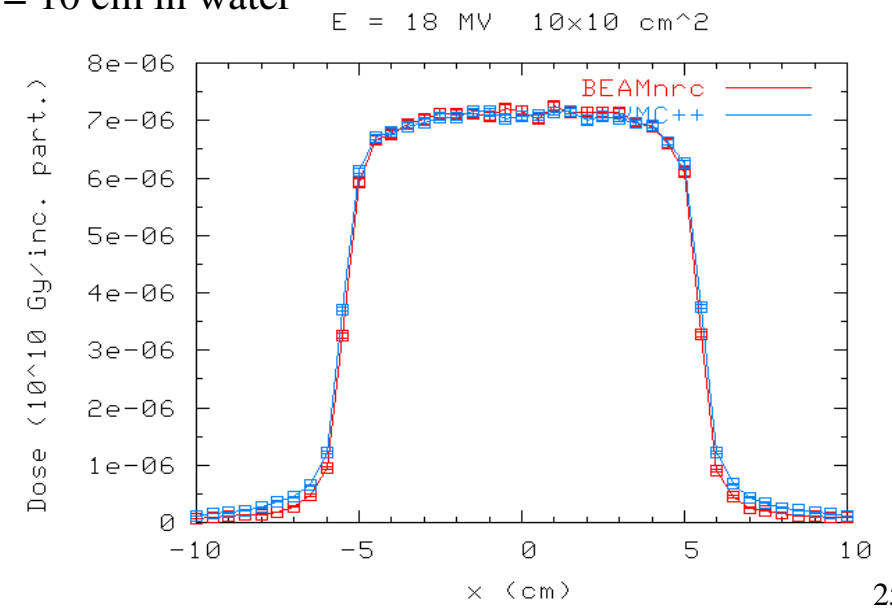




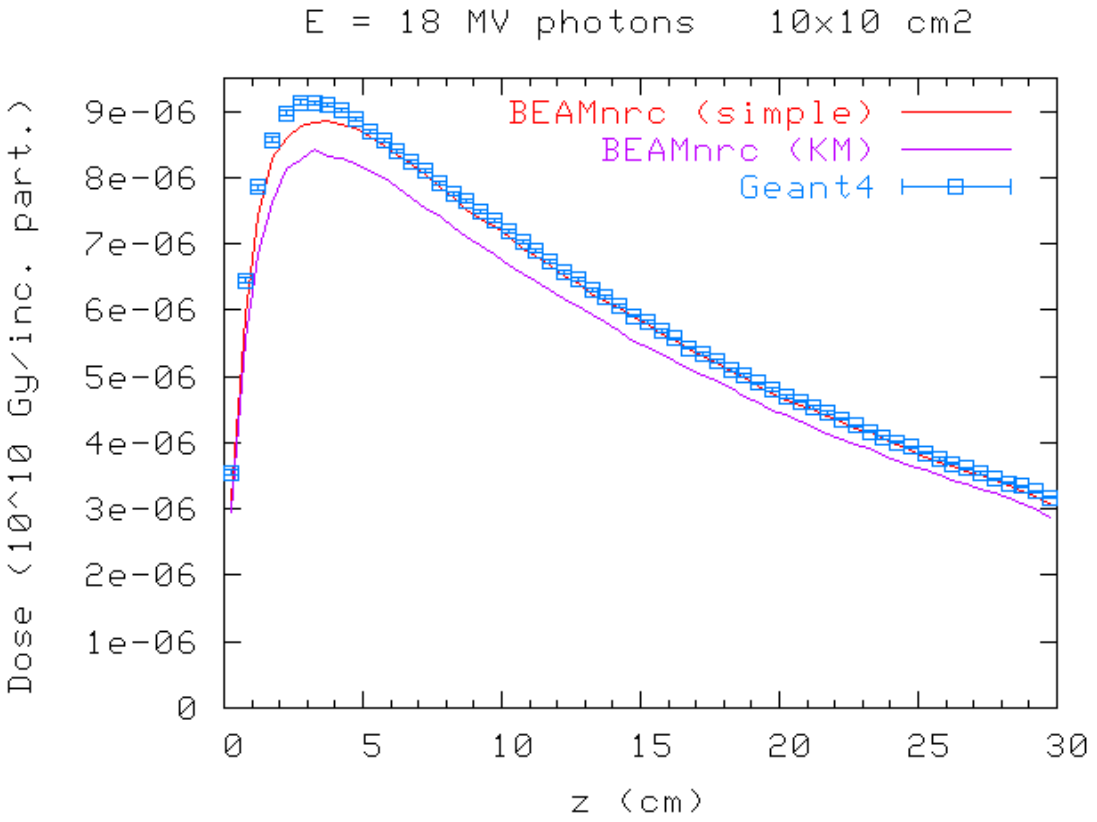
	BEAMnrc	DOSXYZnrc	VMC++
CPU time	13.1 h	6.2 h	25 min
N_case	2.88×10^7	1.09×10^8	1.6×10^7

profiles at z = 10 cm in water





BEAMnrc results depend on the parameters used

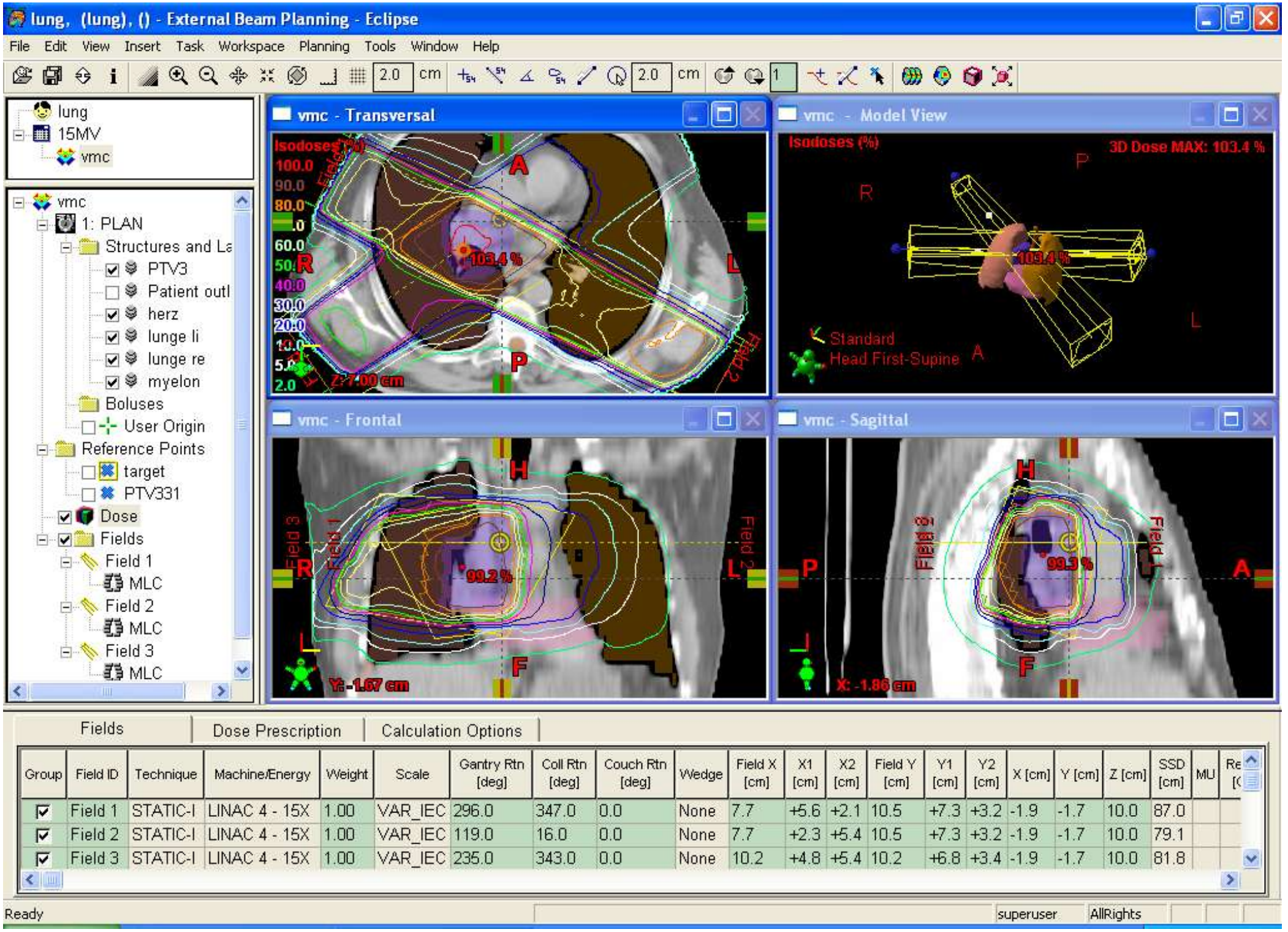


E = 18 MV

Cautionary note: a simple change in the bremsstrahlung distribution from simple to KM (Koch-Motz) produces noticeable changes in the absolute depth dose curves.

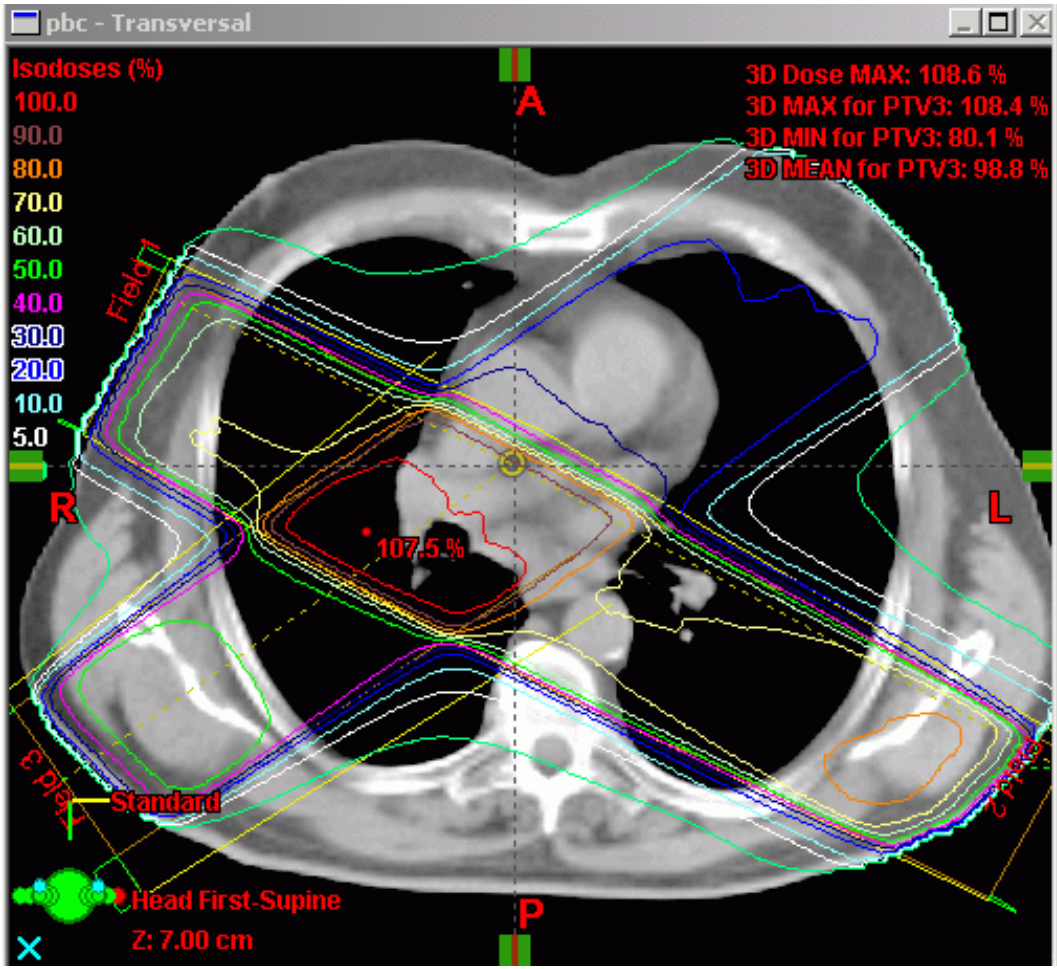
KM (Koch-Motz) uses a whole formula for the distribution of bremsstrahlung photons. Accurate for $E_\gamma > 50$ MeV

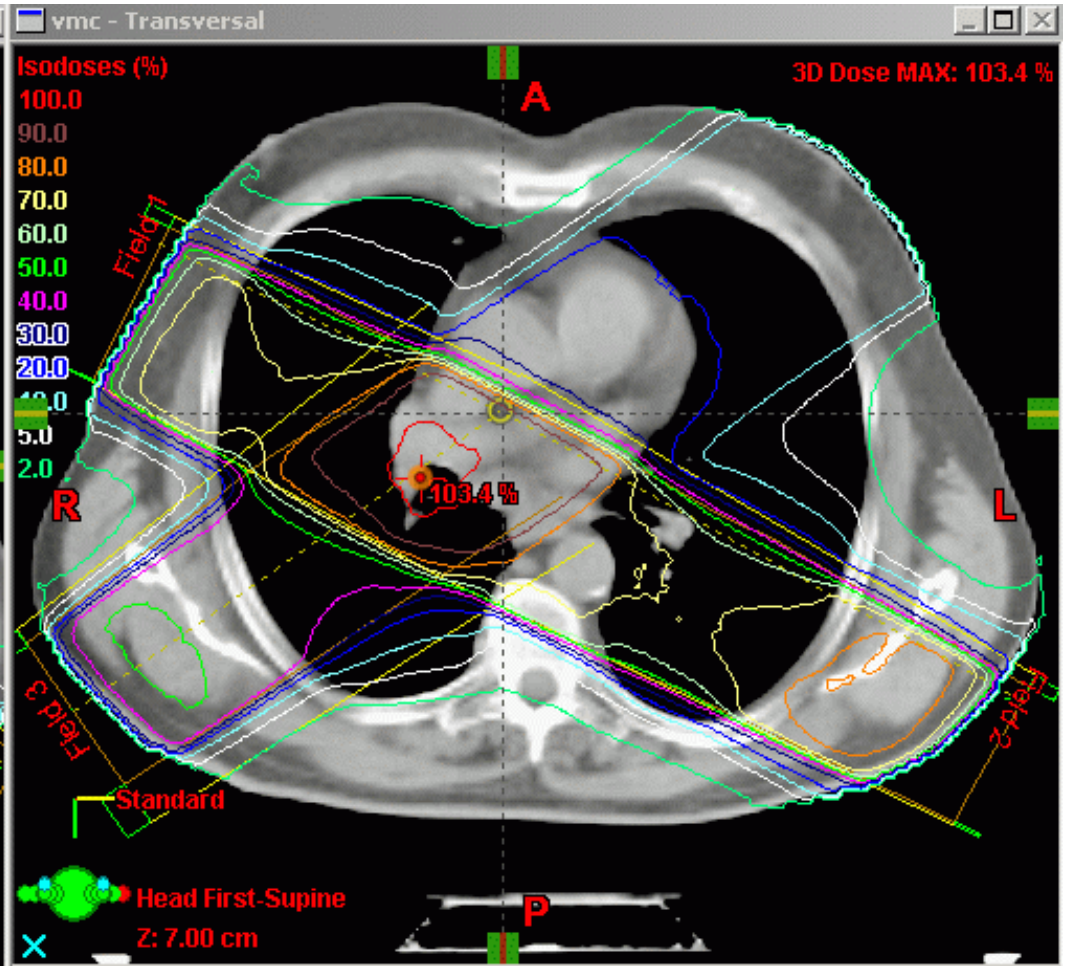
Simple: uses the leading term of the KM expression.


lung, (lung), () - External Beam Planning - Eclipse
File Edit View Insert Task Workspace Planning Tools Window Help
lung
15MV
vmc
vmc - Transversal
vmc - Model View
vmc - Frontal
vmc - Sagittal
Isodoses (%)
3D Dose MAX: 103.4 %
Standard
Head First-Supine
Fields
Dose Prescription
Calculation Options
Group Field ID Technique Machine/Energy Weight Scale Gantry Rtn [deg] Coll Rtn [deg] Couch Rtn [deg] Wedge Field X [cm] X1 [cm] X2 [cm] Field Y [cm] Y1 [cm] Y2 [cm] X [cm] Y [cm] Z [cm] SSD [cm] MU
Field 1 STATIC-I LINAC 4 - 15X 1.00 VAR_IEC 296.0 347.0 0.0 None 7.7 +5.6 +2.1 10.5 +7.3 +3.2 -1.9 -1.7 10.0 87.0
Field 2 STATIC-I LINAC 4 - 15X 1.00 VAR_IEC 119.0 16.0 0.0 None 7.7 +2.3 +5.4 10.5 +7.3 +3.2 -1.9 -1.7 10.0 79.1
Field 3 STATIC-I LINAC 4 - 15X 1.00 VAR_IEC 235.0 343.0 0.0 None 10.2 +4.8 +5.4 10.2 +6.8 +3.4 -1.9 -1.7 10.0 81.8
Ready
superuser
AllRights

Monte Carlo dose computations in treatment planing systems

E = 15 MV





Pencil Beam Convolution

Calculation Grid: 2.5 mm
Inhomogeneity correction: Equivalent TAR
Std Arc Calculation Segment: 14
Arc Normalization: Plan
Isocentric Normalization: Plan
Fixed SSD Normalization: Standard Inverse Square Law

Voxel Monte Carlo

Calculation grid: 2.5mm
N_case = 10^7
Time = 127.2 min

Monte Carlo limitations

Technical limitations:

approximations used in the different transport algorithms

differences in algorithm implementation and physical data used (e.g. cross section tables used)

accuracy versus time efficiency

Experimental limitations:

geometry uncertainties (due to firm secrecy policy)

difficulties in performing the right measurements (detector type, simulation of detector response)

Conclusions/Recommendations

Caveat: there is no exact MC code, all use certain physical approximations within a given range of applicability. Therefore all MC codes need fine tuning of their transport parameters according to the physical application considered.

Possible solution: know your MC code
check ranges of applicability of your particular geometrical problem
(e.g. ionization chamber)

Sources of error: geometry implementation
wrong transport parameters

Recommendations: do systematic, stepwise, thorough tests of your simulation.

All in all MC calculations are by far more accurate than semi-analytical or MC-kernel based dose calculations and CPU time is no longer an obstacle in the clinical implementation of MC techiniques.

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, nuclear criticality safety, Detector Design and analysis, nuclear oil well logging, Accelerator target design, Fission and fusion reactor design, decontamination and decommissioning. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori.

Pointwise cross-section data typically are used, although group-wise data also are available. For neutrons, all reactions given in a particular cross-section evaluation (such as ENDF/B-VI) are accounted for. Thermal neutrons are described by both the free gas and S(alpha,beta) models. For photons, the code accounts for incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation, and bremsstrahlung. A continuous-slowing-down model is used for electron transport that includes positrons, k x-rays, and bremsstrahlung but does not include external or self-induced fields.

Important standard features that make MCNP very versatile and easy to use include a powerful general source, criticality source, and surface source; both geometry and output tally plotters; a rich collection of variance reduction techniques; a flexible tally structure; and an extensive collection of cross-section data.

MCNP5 contains numerous flexible tallies: surface current & flux, volume flux (track length), point or ring detectors, particle heating, fission heating, pulse height tally for energy or charge deposition, mesh tallies, and radiography tallies.

All standard MCNP neutron libraries over their stated ranges.
Neutrons in the LA150 library from 0.0 - 150.0 MeV in tabular range for 42 isotopes
(except for 9Be to 100 MeV).
Neutrons from 1.0 MeV in physics model regime.
Protons from 1.0 to 150.0 MeV in tabular range for 41 isotopes.
Protons from 1.0 MeV in physics model regime.
Pions, muons, and kaons are treated only by physics models.
Photons from 1 keV - 100 GeV.
Electrons from 1 keV - 1 GeV.
Neutrons do not create delayed photons.
Photonuclear interactions from 1.0 to 150.0 MeV in tabular range for 12 isotopes.
Photonuclear interactions from 1.0 MeV in the CEM physics model.

CODING LANGUAGE AND COMPUTER

Fortran 90 and C source code included plus executables for Windows PCs, Linux PCs, MacOSX, Unix systems (Sun Solaris, Alpha OSF & IBM AIX)

PENELOPE performs Monte Carlo simulation of coupled electron-photon transport in arbitrary materials and complex quadric geometries. A mixed procedure is used for the simulation of electron and positron interactions (elastic scattering, inelastic scattering and bremsstrahlung emission), in which 'hard' events (i.e. those with deflection angle and/or energy loss larger than pre-selected cutoffs) are simulated in a detailed way, while 'soft' interactions are calculated from multiple scattering approaches. Photon interactions (Rayleigh scattering, Compton scattering, photoelectric effect and electron-positron pair production) and positron annihilation are simulated in a detailed way.

Electron and positron kinetic energies must be in the range from 100 eV to 1 GeV and plural or multiple scattering conditions have to be fulfilled, i.e. the number of both elastic and inelastic interactions in the material must be larger than about 10.
Photon energies should be in the range from 100 eV (or the M-shell absorption edge, whichever is the largest) to 1 GeV.
Photo-nuclear reactions are disregarded.

Any operating system supporting a FORTRAN 77 compiler. Fortran 90 compatible.

J. Sempau, E. Acosta, J. Baro, J.M. Fernandez-Varea and F.Salvat:
An algorithm for Monte Carlo simulation of the coupled electron-photon transport.
Nuclear Instruments and Methods B 132 (1997) 377-390.