Abteilung für Medizinische Strahlenphysik
Inselspital, Universität Bern, Schweiz
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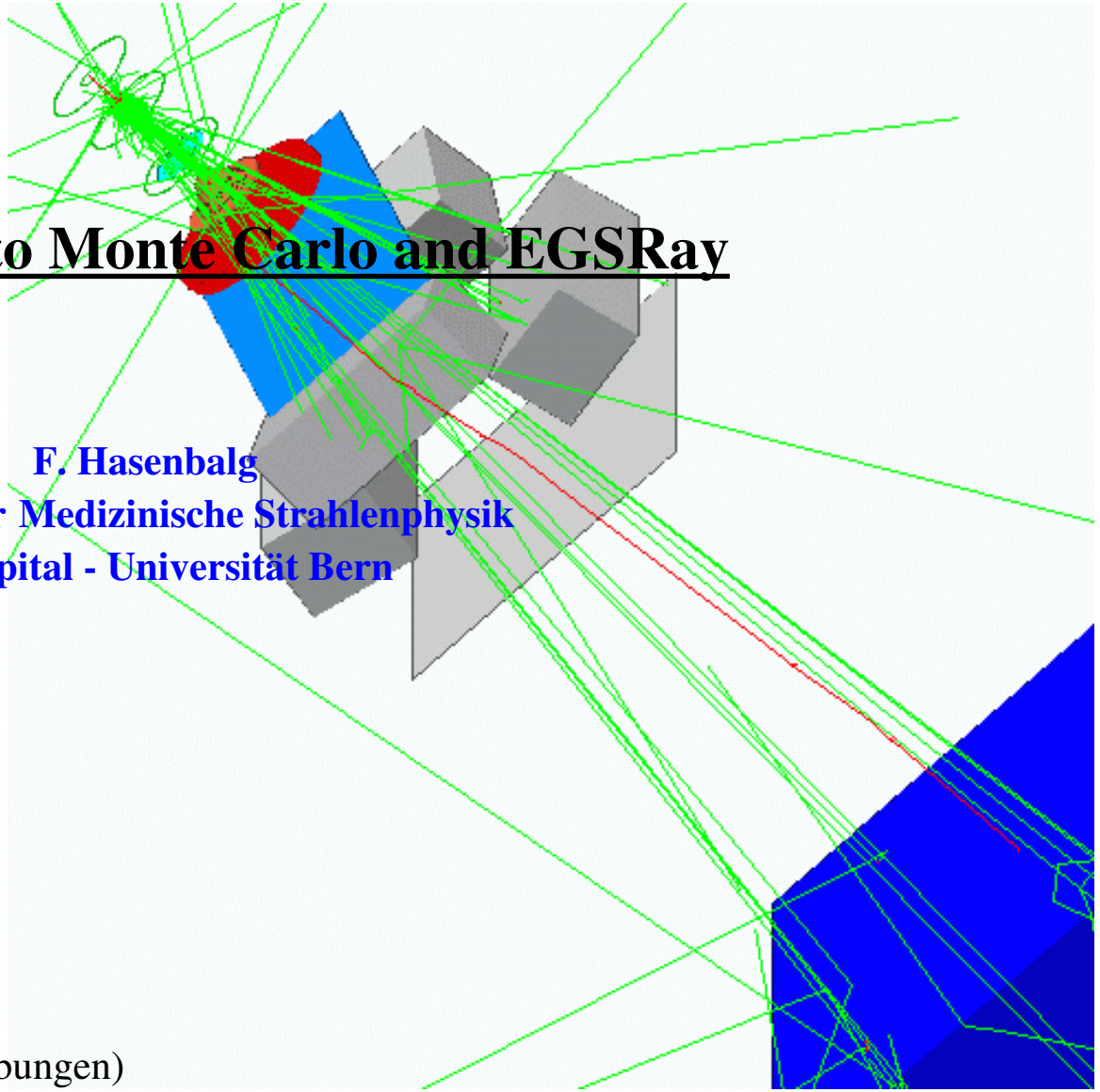
Introduction to Monte Carlo and EGSRay



F. Hasenbalg
Abteilung für Medizinische Strahlenphysik
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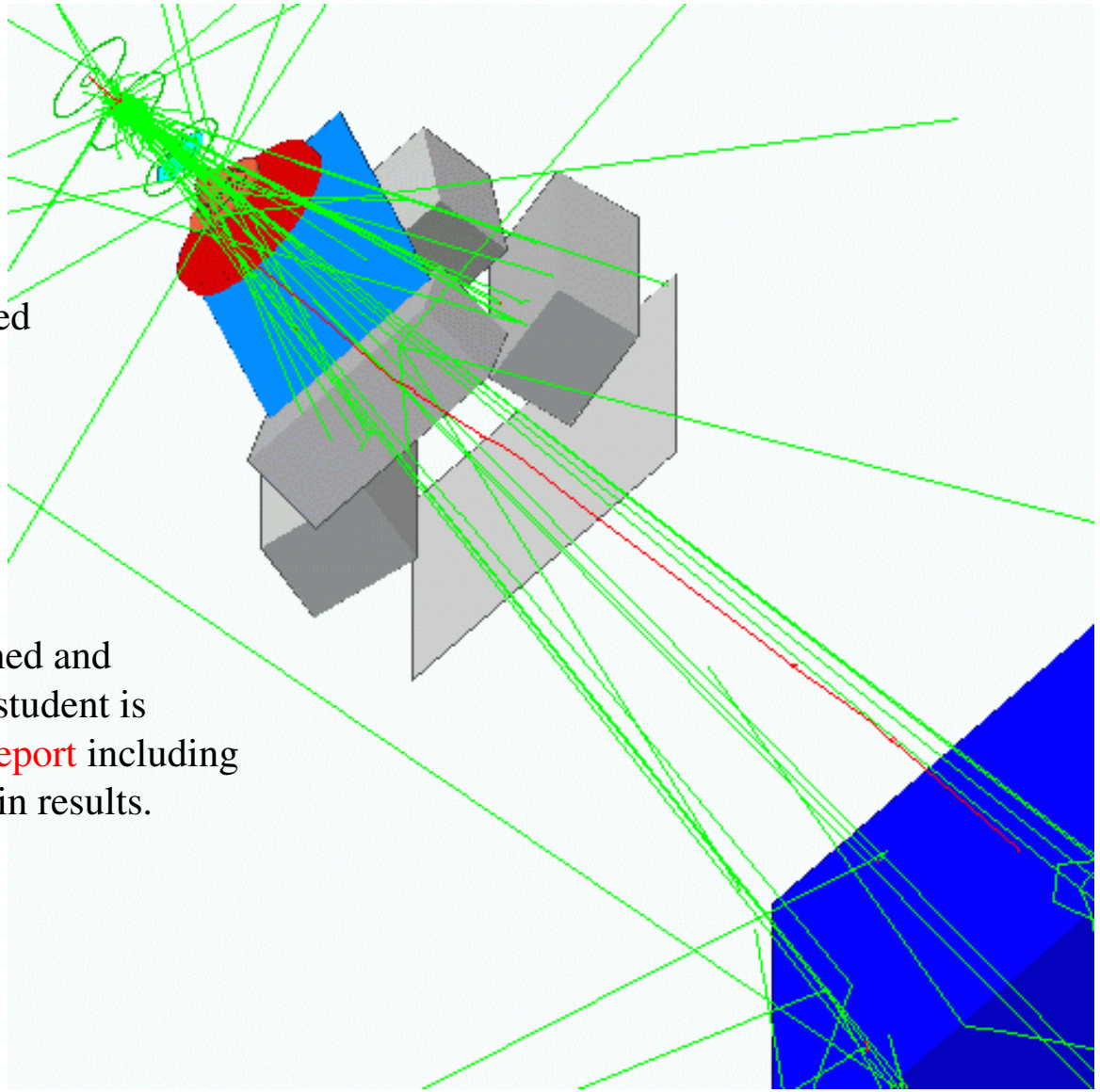
Medizinische Physik Übungen

Lecturer: Roberto Mini

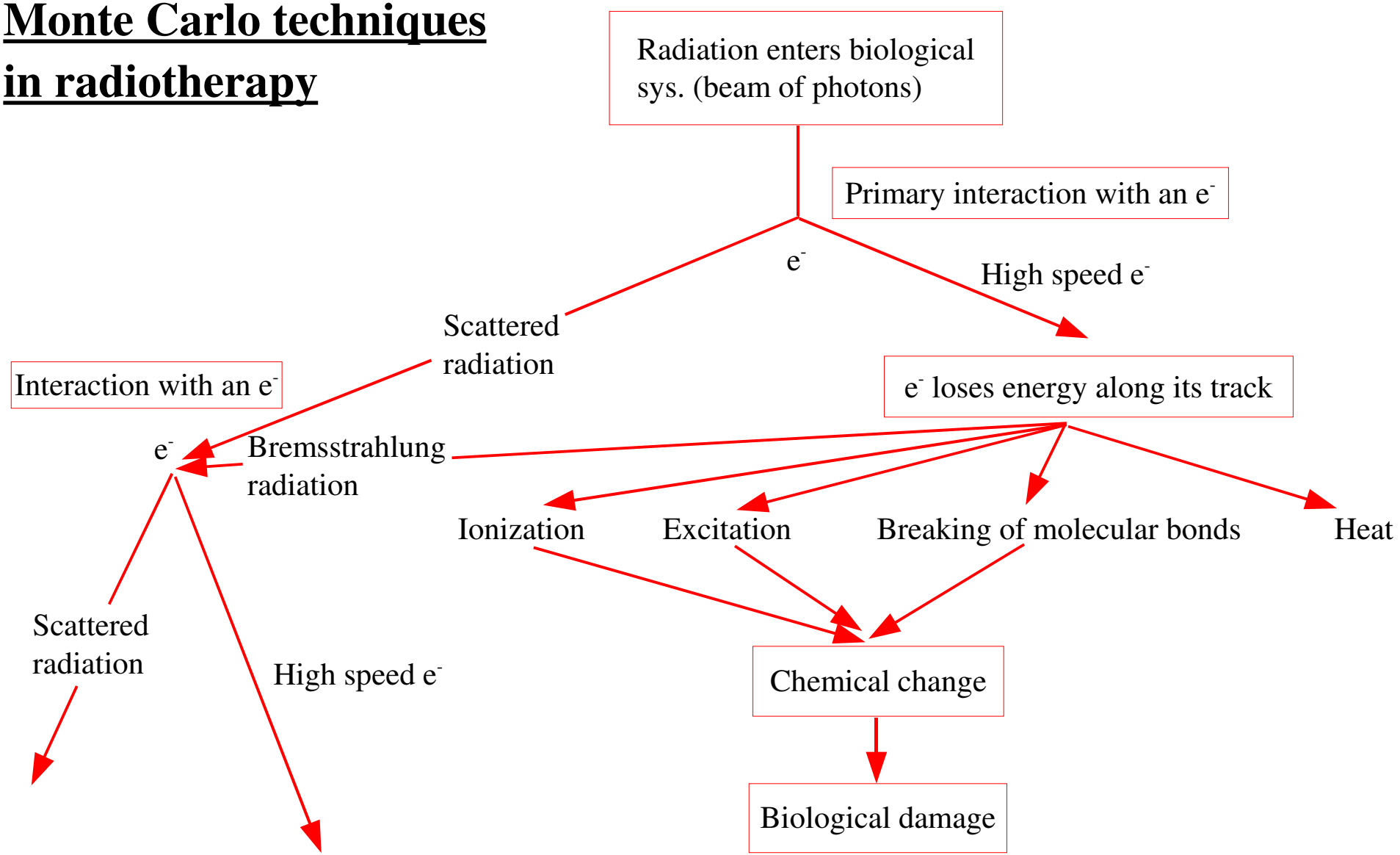
Main goal of the course is the use of
a simple Monte Carlo program (EGSRay)
as a tool to illustrate the concepts introduced
in the theoretical lessons.

It is not the aim of this course to become
experts in Monte Carlo!

Each week a new homework will be assigned and
after running the simulations at home, the student is
expected to write a brief and quantitative report including
graphs and simulation outputs with the main results.

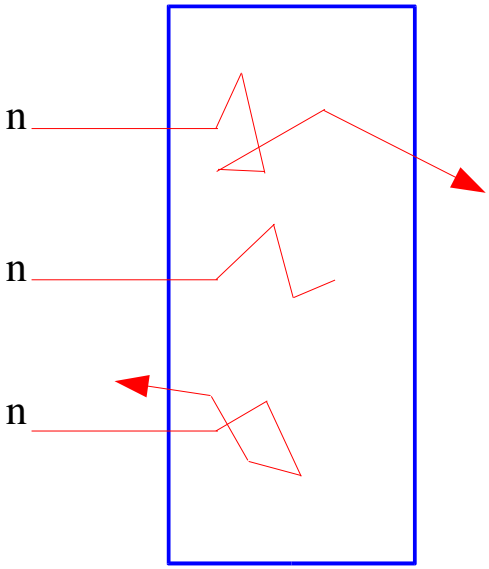


Monte Carlo techniques in radiotherapy



Simple example of a Monte Carlo problem

Elastic scattering of neutrons in a slab of material



σ_{cap} , σ_{dis} : capture and dispersion cross sections are properties of the material.

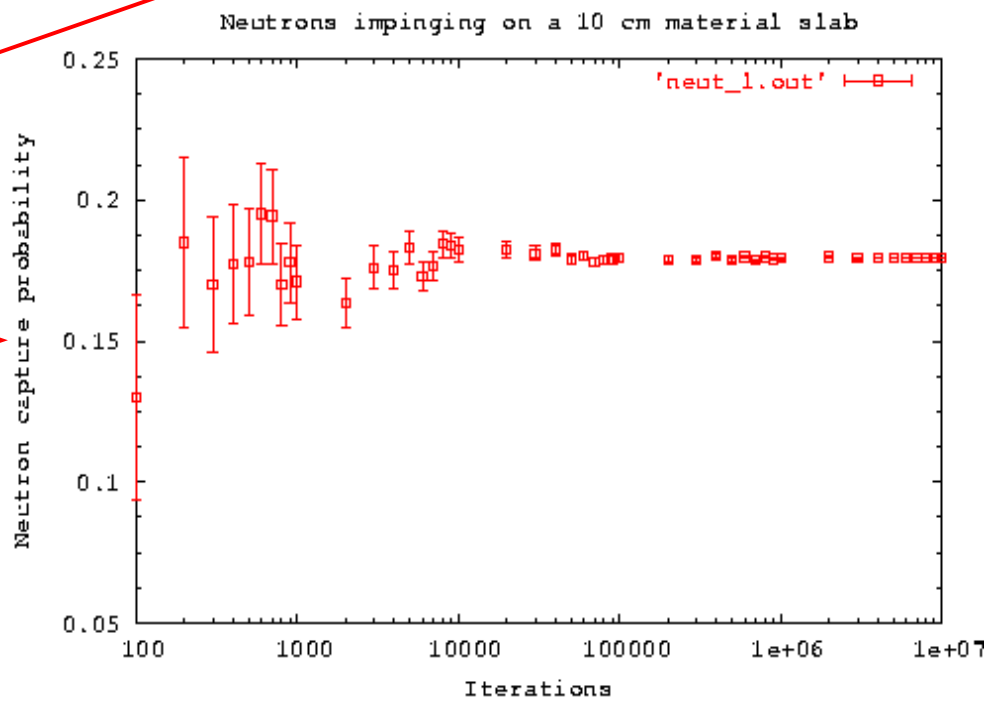
Mean free path -> exponential probability distribution

$p(x) = \sigma \exp(-\sigma x)$ $\quad \sigma = \sigma_{cap} + \sigma_{dis}$

Sampling of an exponential p.d.f :

$$\lambda = -(1/\sigma) \ln \gamma$$

γ is a uniform prob. distribution (0,1), random number generator.



General considerations of Monte Carlo codes

Geometry and media: definition of the geometry, particles involved and media through which the particles are to be transported.

Sampling of probability distributions: use of pseudo random number generators to obtain probability distributions relevant to the physical problem.
Generation of secondary particles.

Random number generators: produce random numbers uniformly distributed in the interval (0,1) with periods larger than 10^{43}. Several methods e.g. multiplicative congruential method, for more details see: Numerical Recipes, W. H. Press et al.

Transport: follow-up of the fate of particles and transport them as they travel through different media.

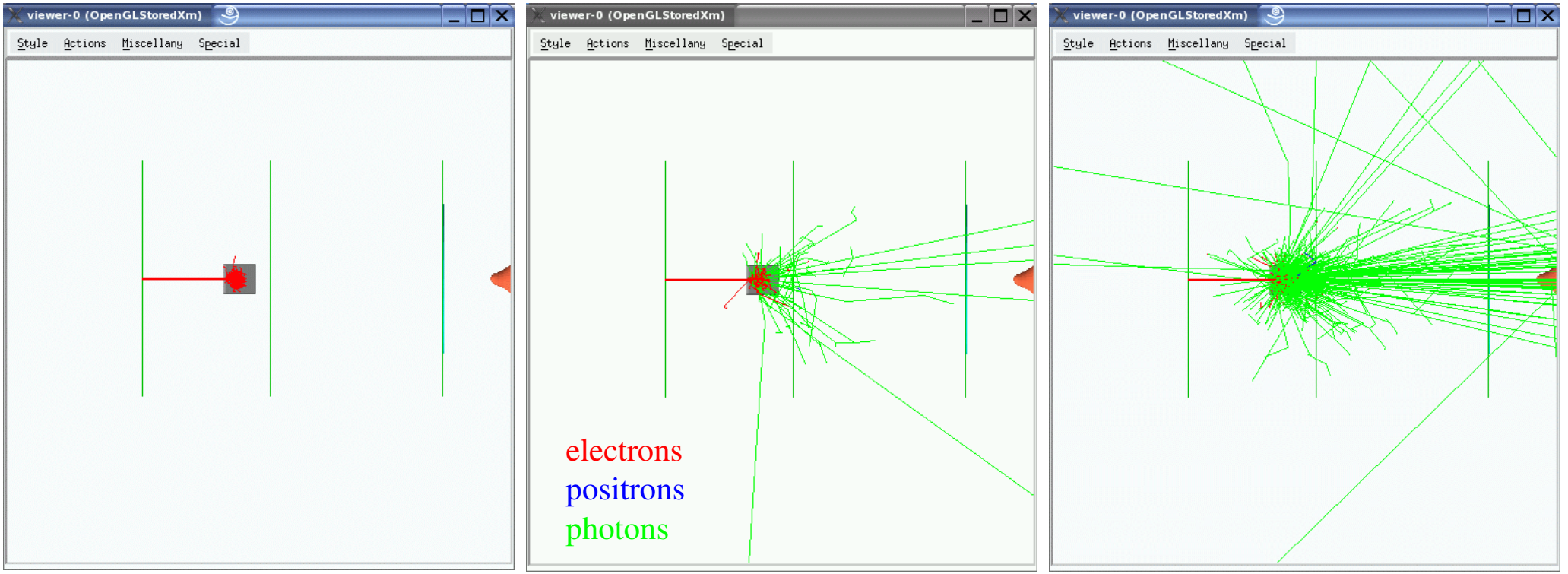
Simple example:

Geometry and medium: consider 1 MeV photons impinging on a water phantom
Sampling: after traveling a certain length (mean free path) we decide whether the photon interacts or not in the medium. Once an interaction has taken place, the fate of the photon and secondary particles has to be simulated. Sampling of angular distributions.
Transport: we follow all particles until they have left the geometry defined.

General considerations of Monte Carlo codes

Cut-off of secondary particles

18 MeV electrons impinging on a W+Cu target

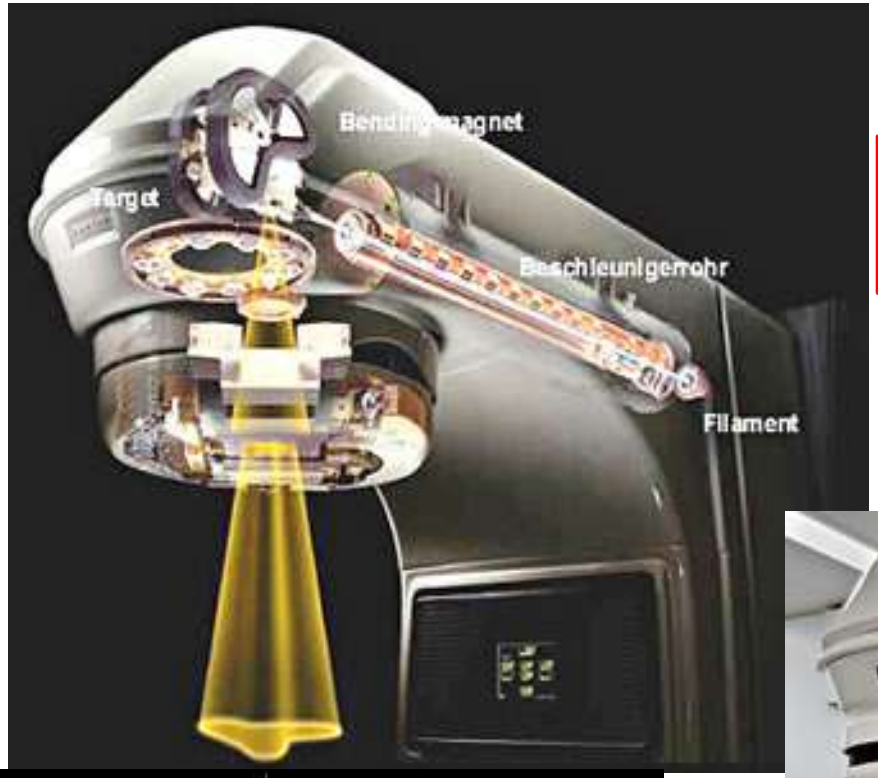


- The lower the cut-off in energy the more particles are produced
- More accuracy at the expense of computing time

Monte Carlo in radiotherapy

Head simulation

- Target + collimator
- Flattening Filter
- Ionization chamber
- Jaws
- MLC
- Beam



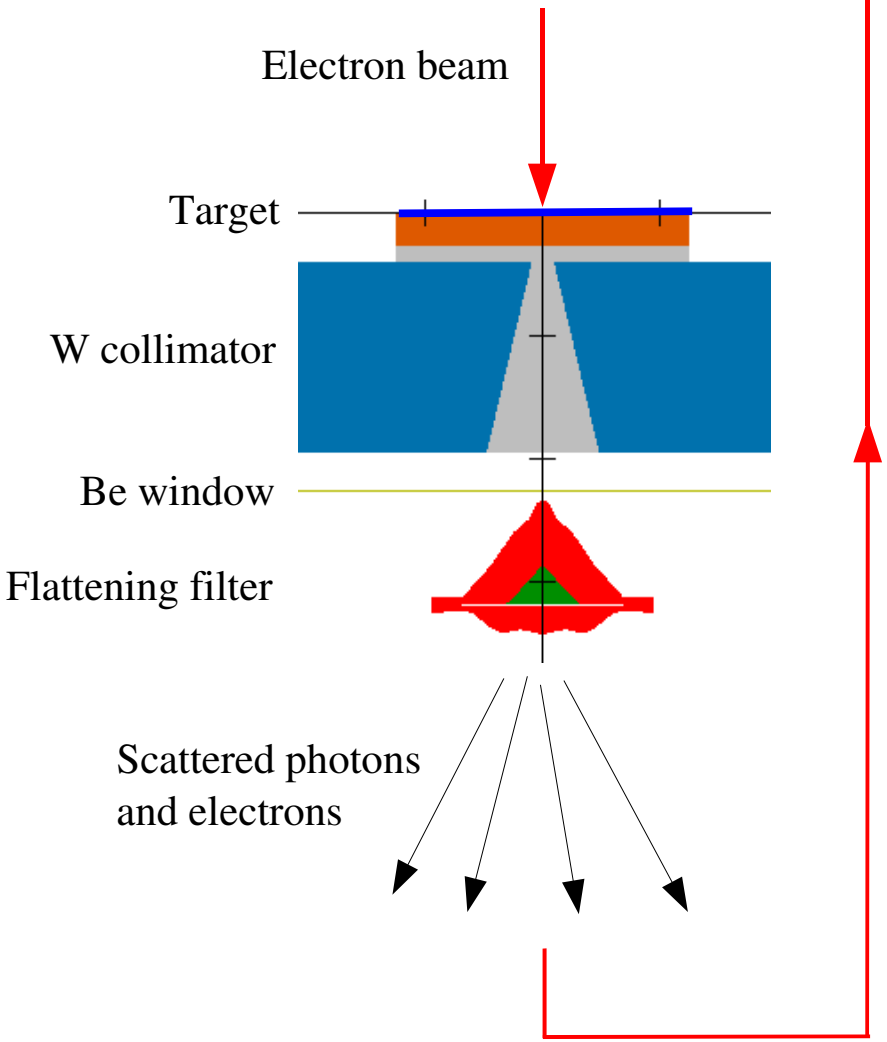
Detailed knowledge of the geometry and materials

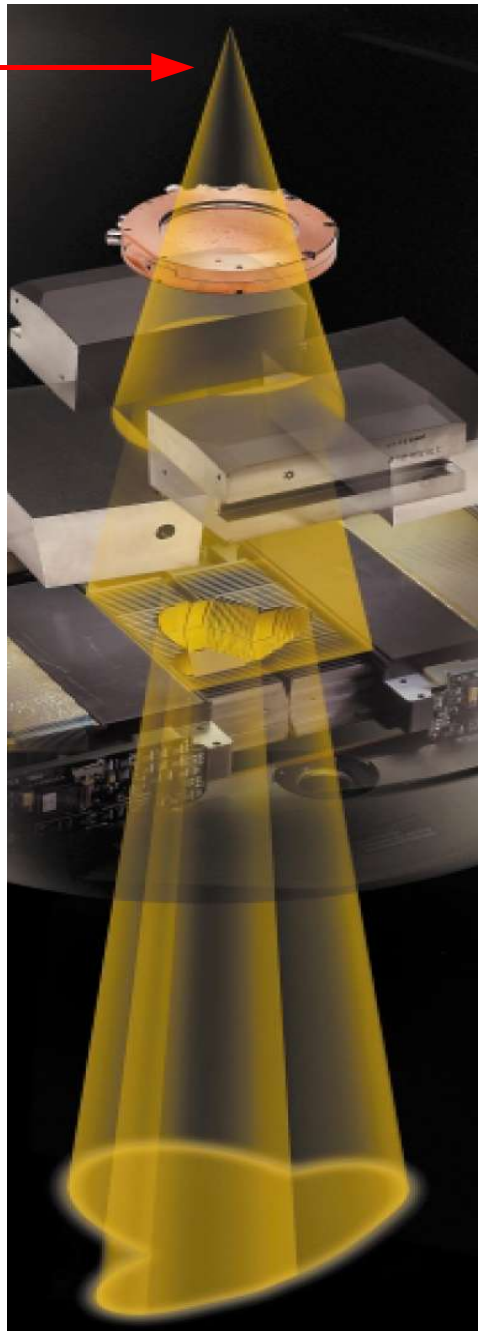
Patient simulation

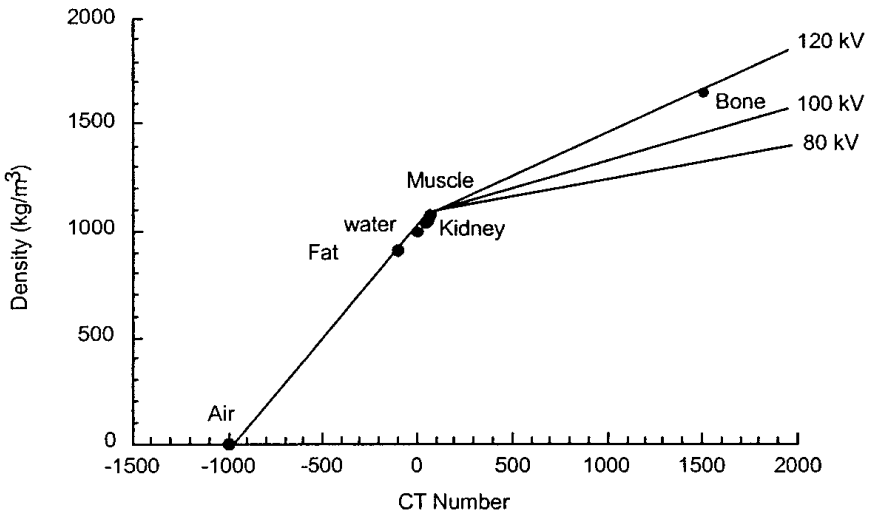
- Patient
- HU to ρ and Z conversion

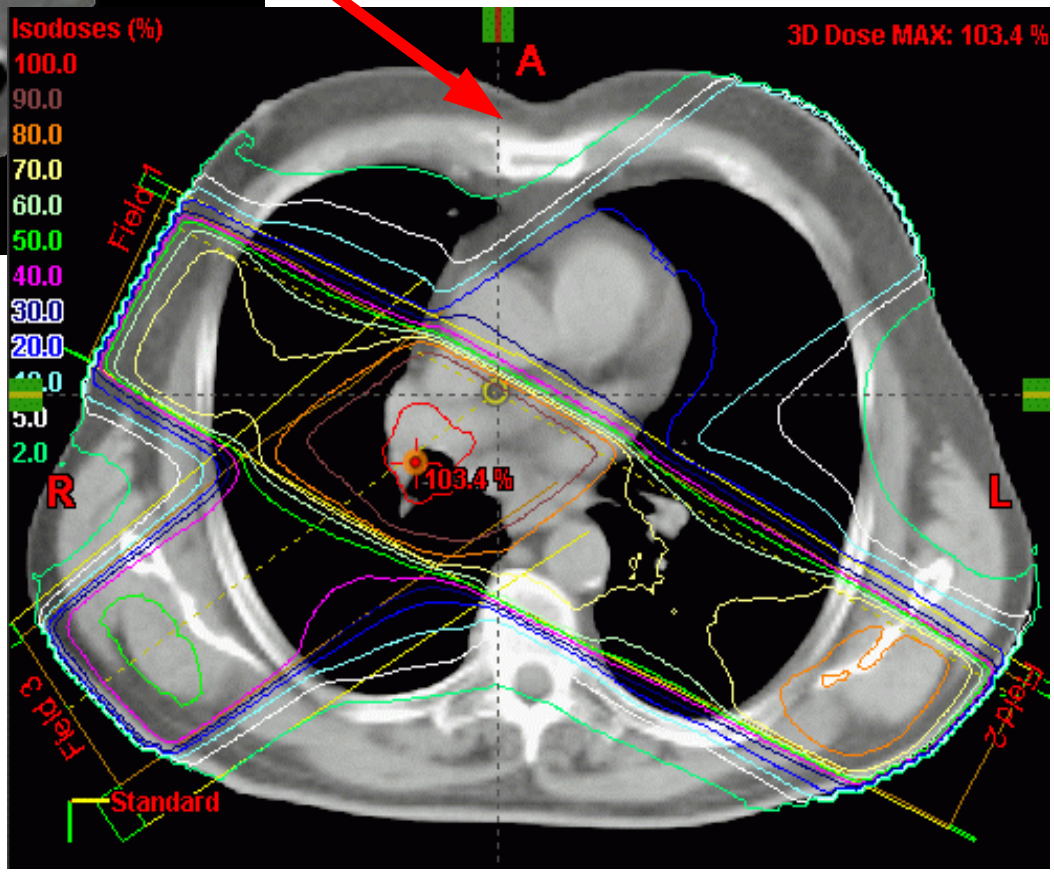
Head simulation

18 MV photon beam (Vendor specific)





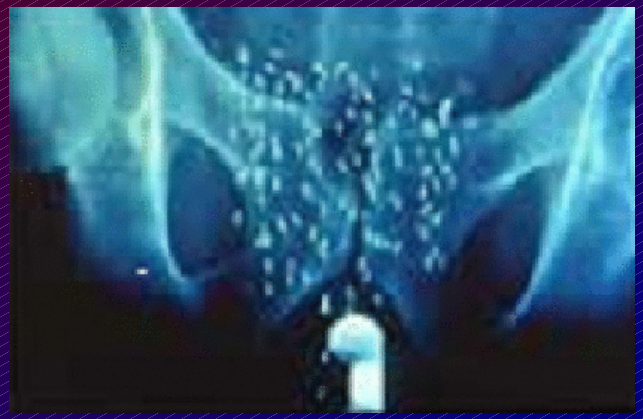

2000
1500
1000
500
0
Density (kg/m3)
-1500
-1000
-500
0
500
1000
1500
2000
CT Number
120 kV
100 kV
80 kV
Bone
Muscle
water
Kidney
Fat
Air


Isodoses (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
5.0
2.0
3D Dose MAX: 103.4 %
A
R
L
103.4 %
Field 1
Field 3
Field 2
Standard

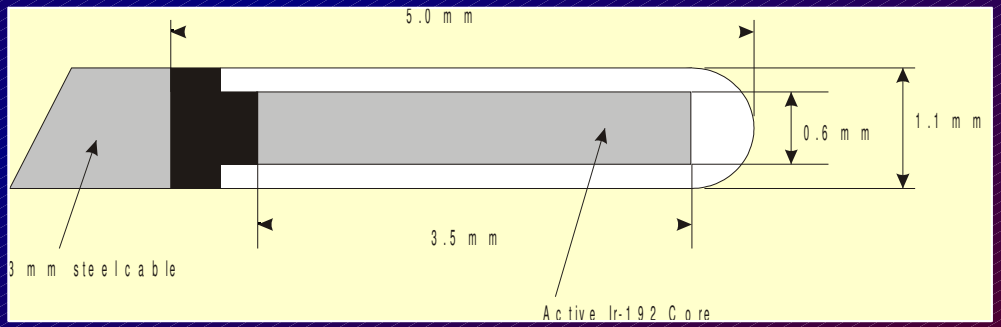
Brachytherapy

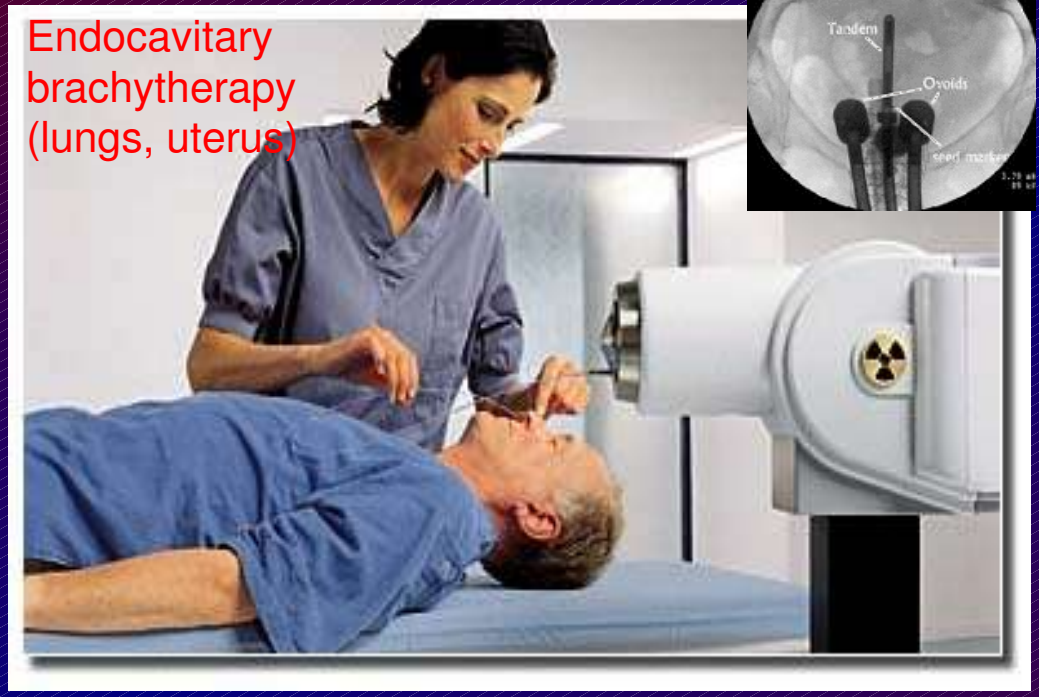
- Brachytherapy is a medical therapy used for cancer treatment

Radioactive sources are used to deposit therapeutic doses near tumors, while preserving surrounding healthy tissues



Interstitial brachytherapy (prostate)

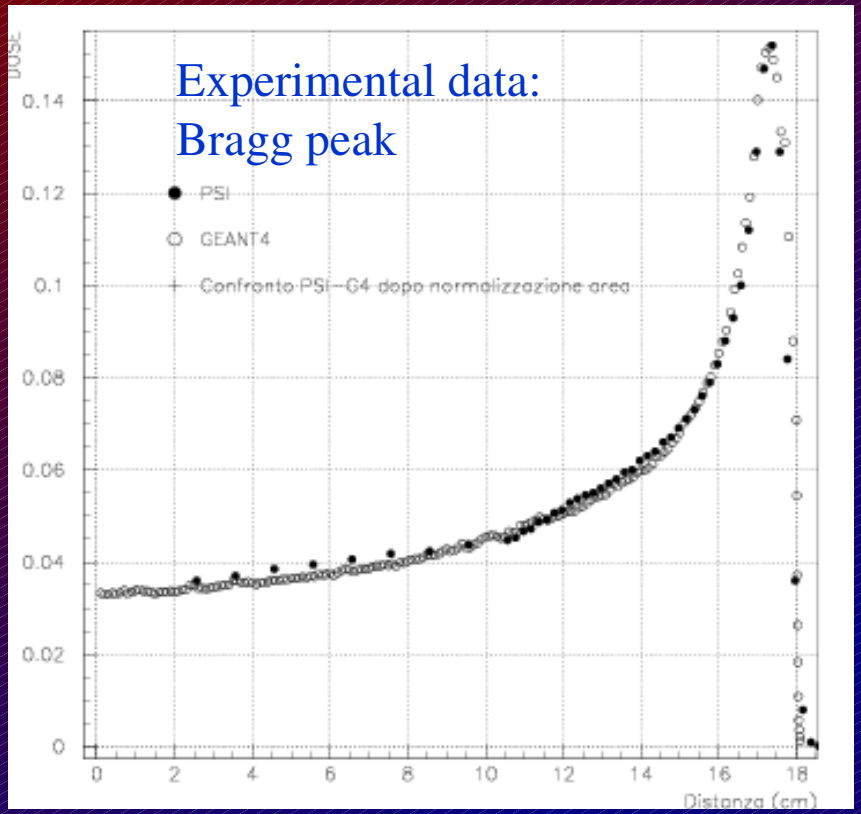


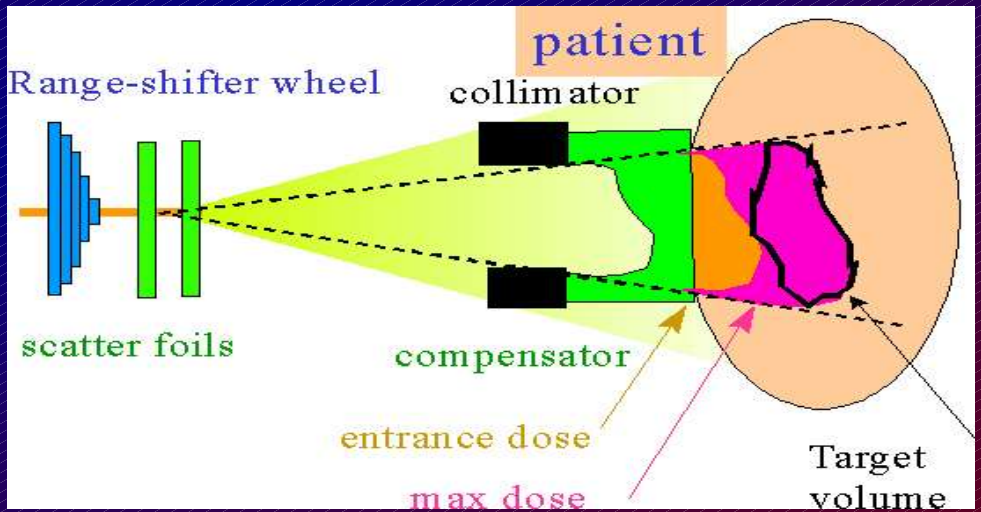


- Treatment planning: how to set (where?, how long?) radioactive sources in treatment's target area
- Software is used to define patient's treatment planning
- It calculates the dose in the patient

Protontherapy

radmed.web.psi.ch/asm/gantry/gantry_master.html





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)

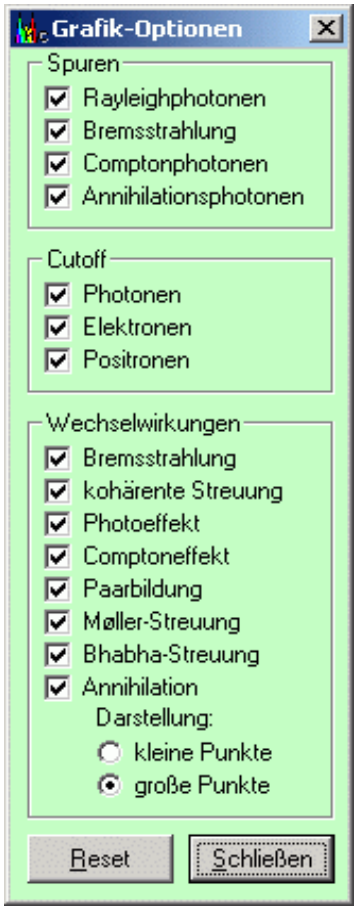
- γ: Coherent scattering (Rayleigh scattering, ~$Z^{2.5}$)
  - Photoelectric effect (~$Z^{4.5}$)
    - Auger electrons
    - Characteristic x-rays
  - Compton scattering (incoherent scattering, ~Z)
  - Pair production with screening (in the field of a nucleus, ~Z^2)
    - Triplet production (pair prod.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



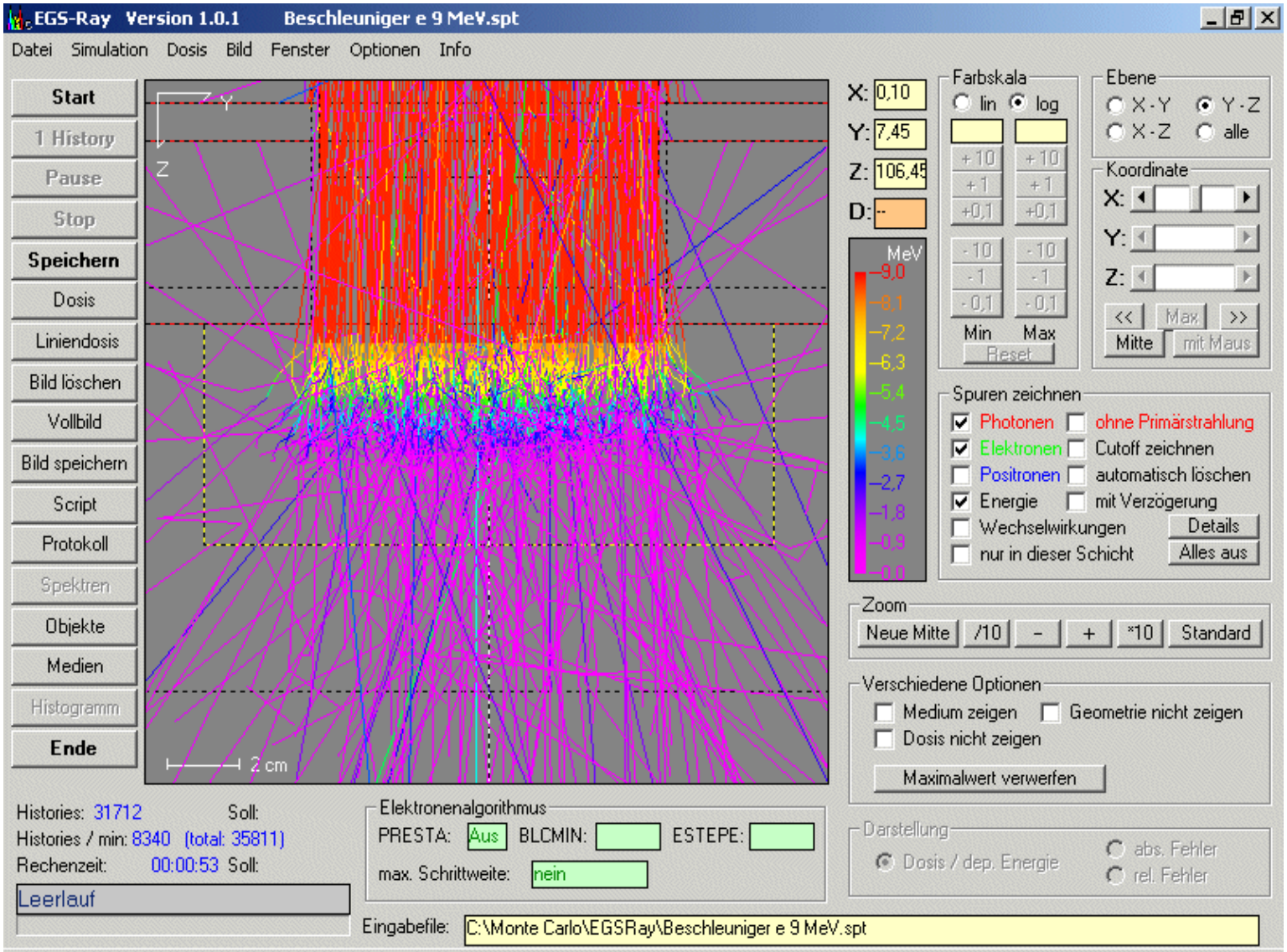
EGS-Ray

Version 1.0.1

Dr. Christoph Kleinschmidt
Städtische Kliniken Köln-Merheim

www.uni-koeln.de/~airm7/EGSRay/index.html

Installation instructions and link to download site:
www.ams.unibe.ch
-> Lehre
-> Vorlesungs Unterlagen
-> Medizinische Physik I, übungen
-> Download des EGSRay Program



EGS-Ray ist eine Umsetzung des bekannten Monte-Carlo-Codes EGS4 für Windows-PC ohne großen Aufwand

Man kann mit EGS-Ray

* Photonen, Elektronen oder Positronen Quellen definieren als Punktquellen oder Felder

* Isotrope oder gerichtete Strahlenquellen definieren

* Feste Energien oder Spektren benutzen

* Energiedosis oder deponierte Energie berechnen

* Beiträge der Teilchengenerationen (Primär-, Sekundärstrahlung usw.) separat ermitteln

* Die Orte von Wechselwirkungen und Cutoff zeichnen lassen

* Den Elektronencode PRESTA an- oder ausschalten

* Histogramme von Teilcheneigenschaften beim Durchgang durch eine Fläche

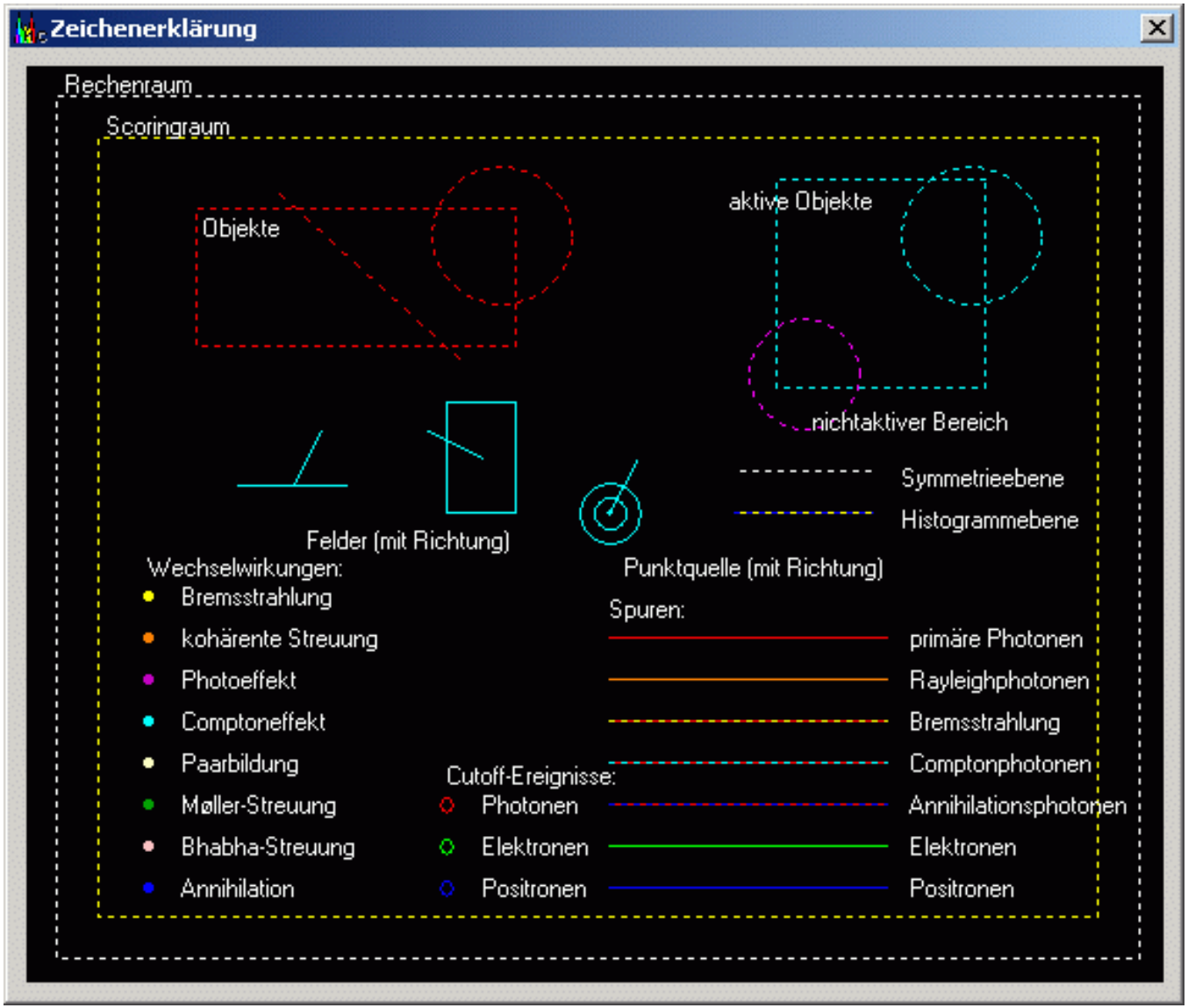
* Dosisergebnisse als MS-Excel-Datei exportieren

* Ergebnisse früherer Rechnungen auf den Bildschirm holen und auswerten

PRESTA

Parameter **R**educed **E**lectron
Step **T**ransport **A**lgorithm

- low energy algorithm
- accurate description of multiple scattering
- lateral diffusion
- boundary crossing algorithm



EGS-Ray

Input file for a simple example

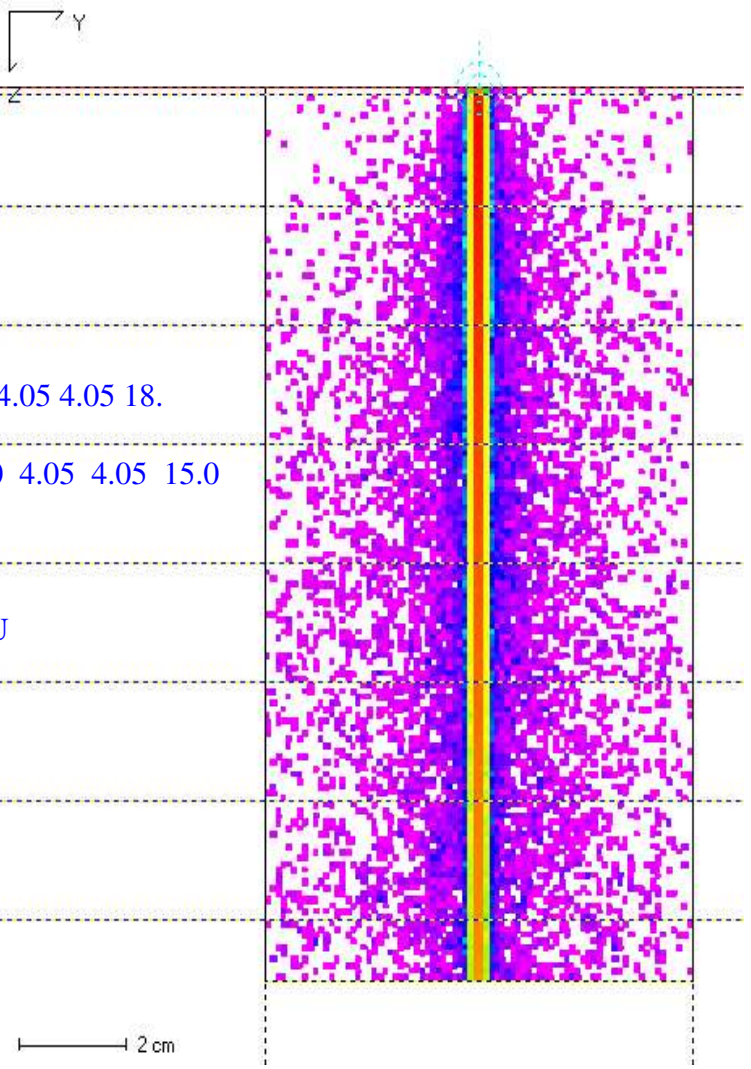
Data tables: PEGS4 (Preprocessor for EGS4)

Particle Sources: Punkktquelle
Feld
Photonen, Elektronen, Positronen
Energie, Spektrum
Richtung, Richtungsbereich
Gewicht

Geometry: Raum, Halbraum
Platte
Box
Kugel
Ellispsoid
Zylinder
Kegel
Flächenobjekt

Mediumname

```
Daten
C:\EGSRay\Mediendaten\521icru.dat
Randomseed
1802 9373
Punktquelle
0. 0. 0.
Richtung
0 0 1
Photonen
Energie
1.00
Rechenraum
-4.05 -4.05 0 4.05 4.05 18.
Scoringraum
-4.05  -4.05  0  4.05  4.05  15.0
Voxelgrösse
0.1 0.1 0.1
Halbraum
H2O521ICRU
2 0 1
Histogramm
2 0.1
Histogramm
2 2.0
Histogramm
2 4.0
.....
```



Data Analysis: Scoringraum
Voxelgrösse
Histogramm
Energiedosis
Deponierte Energie

Program control:

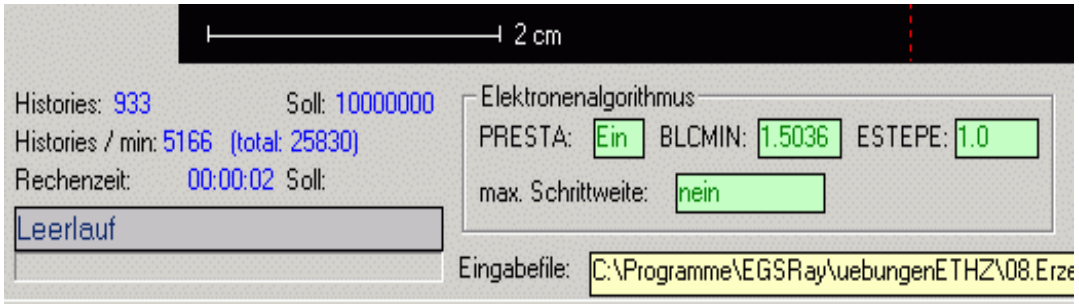
General:
- Histories
- Rechenzeit
- Rechenraum
- Batch
- Keine Dosis

Physics:
- ECUT, PCUT
- ECUTGlobal, PCUTGlobal
- Particlesplitting
- PRESTA
- ESTEPE
- BLCMIN
- Maxstep
- Voxelstep
- Randomseed

Input file for a simple example

```
Daten
C:\Programme\EGSRay\521icru.dat
Randomseed
1802 9373
....

Scoringraum
-4.05  -4.05  0  4.05  4.05  15.0
Voxelgrösse
0.1 0.1 0.1
Halbraum
H2O521ICRU
2 0 1
Histogramm
2 0.1
Histogramm
2 2.5
Histogramm
2 5.0
.....
Presta
```



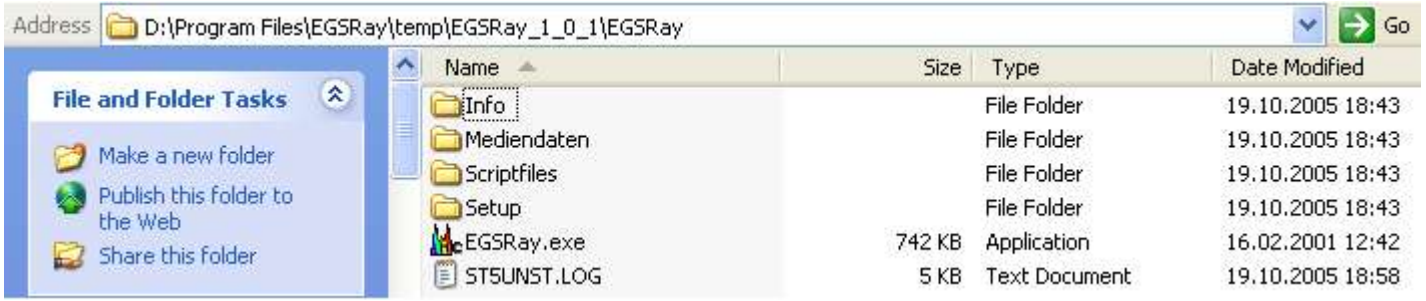
After extracting the EGSRay_1_0_1.zip file it creates the following directory tree

EGSRay_1_0_1
- EGSRay
  - Info
  - Mediendaten
  - Scriptfiles
  - Setup

Goto Setup and execute SETUP.EXE to install EGSRay

Define where you want EGSRay to be installed (e.g. in the same directory)

This creates the executable EGSRay.exe which is ready to work !



Note: in order to test the program using script files you will have to define (with a simple text editor) the right path were EGSRay should look for the Media data files (e.g. in \EGSRay_1_0_1\EGSRay\Mediendaten\521icru.dat)

A short manual (Kurzanleitung.txt) and a detailed manual (EGS-Ray Anleitung V.1.0.doc) are found in \EGSRay_1_0_1\EGSRay\Info

It is highly recommended that you print both of them

Assignment 01

Download and install EGSRay using the correct path in the script files

Bring the program to work!

Print the EGSRay manual: EGS-Ray Version 1.0 Anleitung.doc

First Assignment: (to be completed in 2 weeks)
Based on the already explained example,

Simulate: Electrons E = 1, 10 MeV
Photons E = 1, 10 MeV
Pencilbeam
impinging on a water phantom
scoring dimensions and voxel size adapted to each case
histograms at intervals of 0.5 cm
enough statistics (≈ 10^6 particles)

Analysis: Depth dose curves
Profiles at several depths
Qualitative differences between electrons and photons

GNUPLOT plotting utility program
www.gnuplot.info
-> download
-> gnuplot on sourceforge, section Files.
sourceforge.net/project/showfiles.php?group_id=2055
-> Download gp400win32.zip