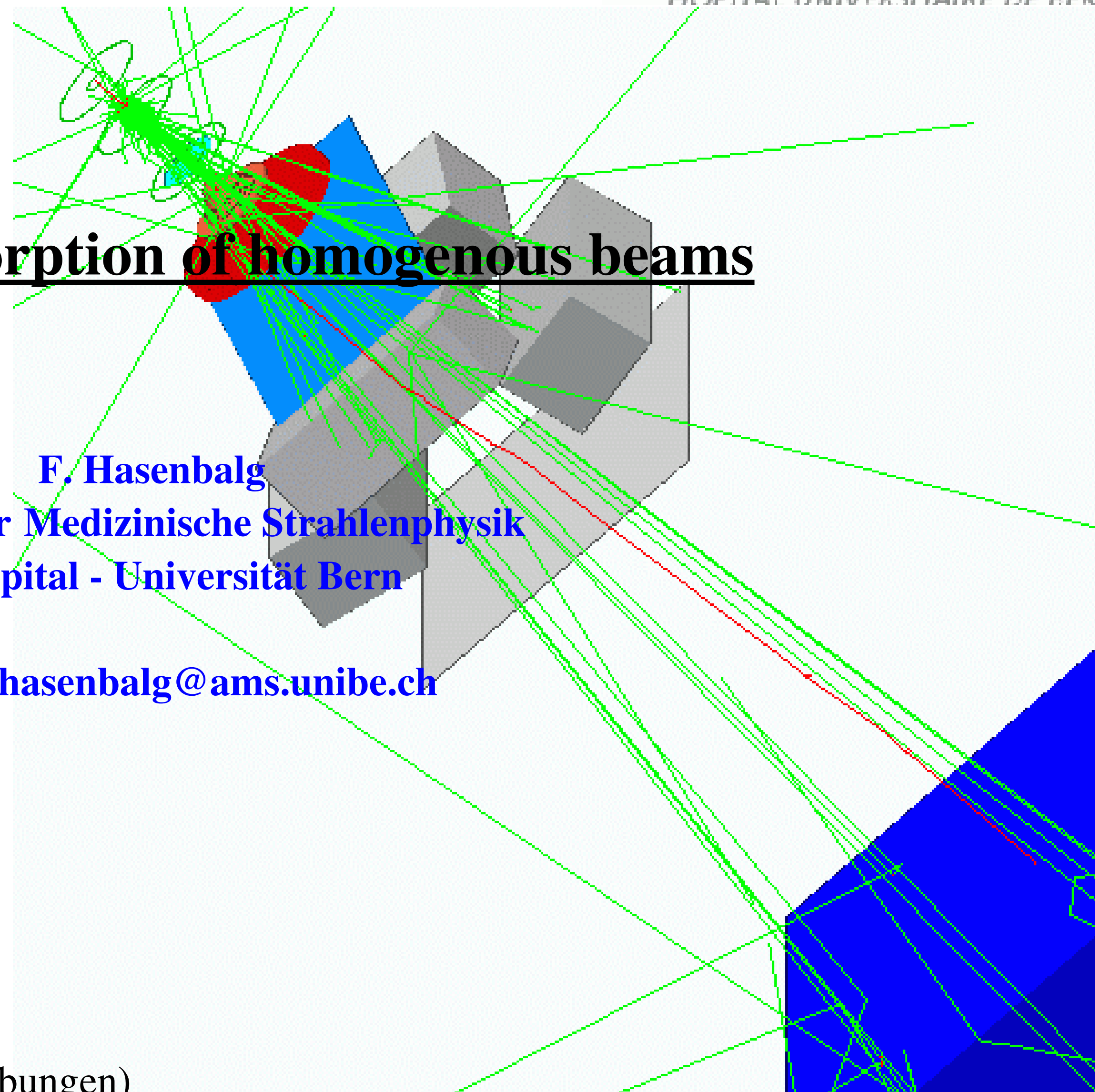
Photon absorption of homogenous beams



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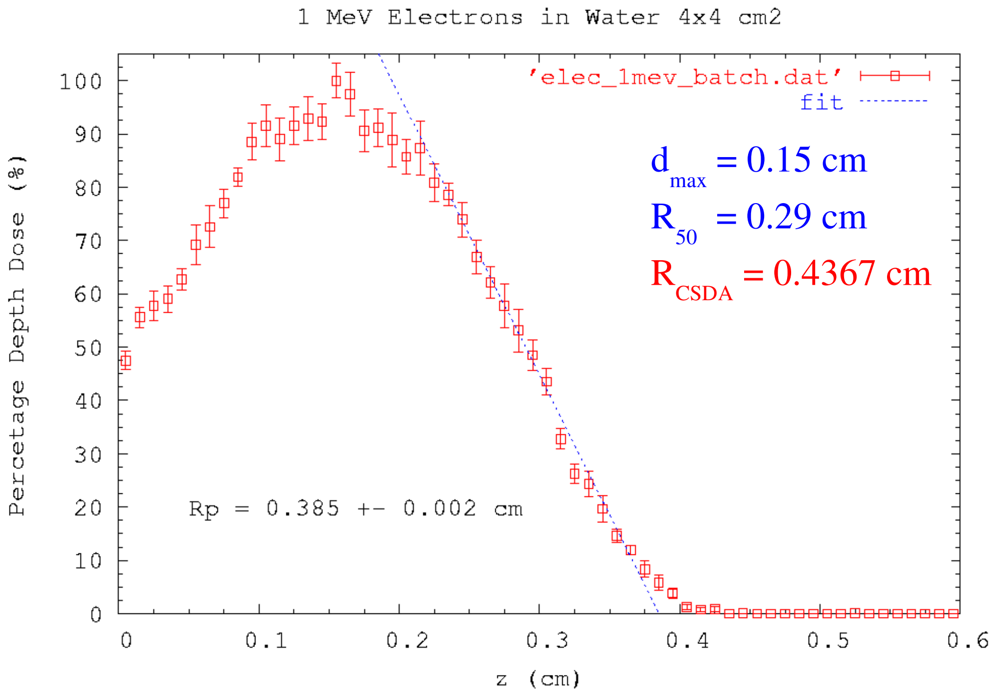
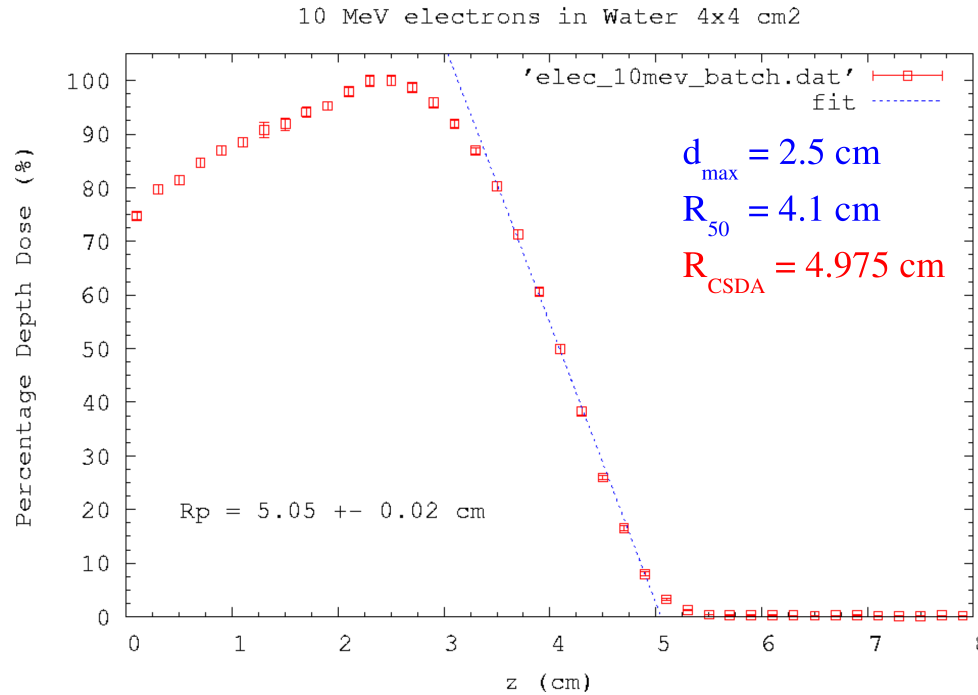
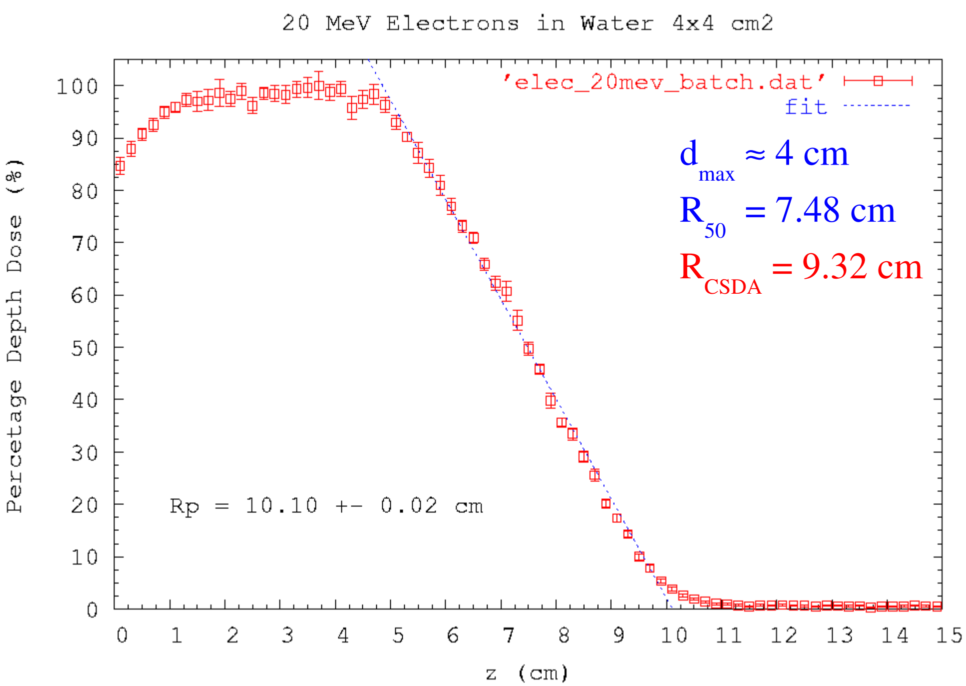
Results assignment 02: electrons 4x4 cm^2 field

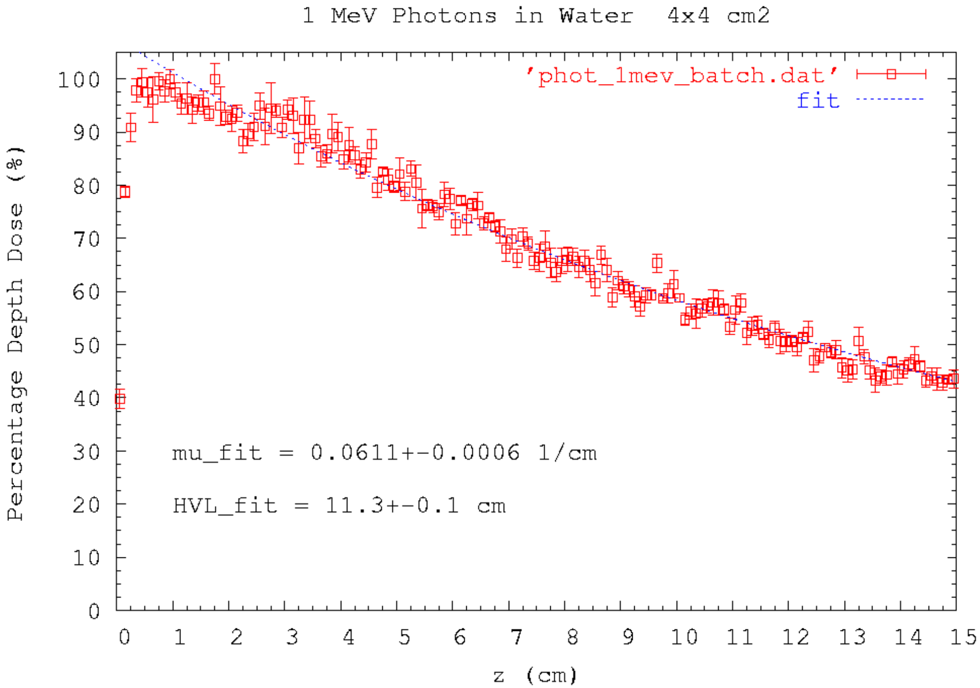


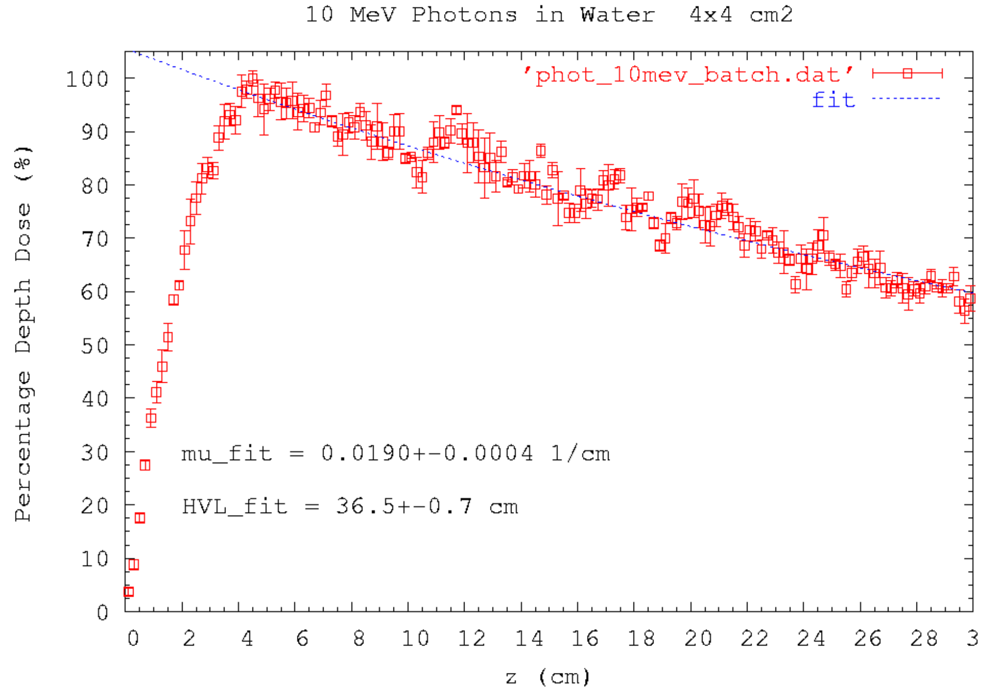


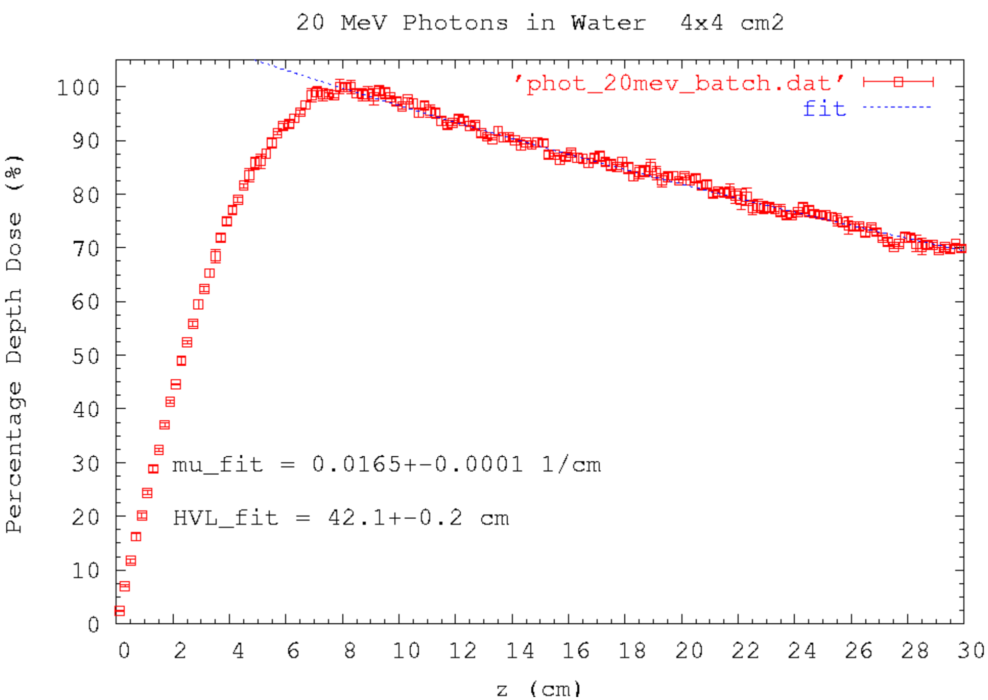


	Pencil beam	4x4 cm^2 field	Table values
1 MeV	d_{max} = 0.08 cm R_{50} = 0.15 cm	d_{max} = 0.15 cm R_{50} = 0.29 cm R_p = 0.385 ± 0.002 cm	R_{CSDA} = 0.4367 cm
10 MeV	d_{max} = 0.5 cm R_{50} = 1.3 cm	d_{max} = 2.5 cm R_{50} = 4.1 cm R_p = 5.05 ± 0.02 cm	R_{CSDA} = 4.975 cm
20 MeV	d_{max} = 0.7 cm R_{50} = 2.1 cm	d_{max} = 4 cm R_{50} = 7.48 cm R_p = 10.10 ± 0.02 cm	R_{CSDA} = 9.32 cm

Results assignment 02: photons 4x4 cm^2 field





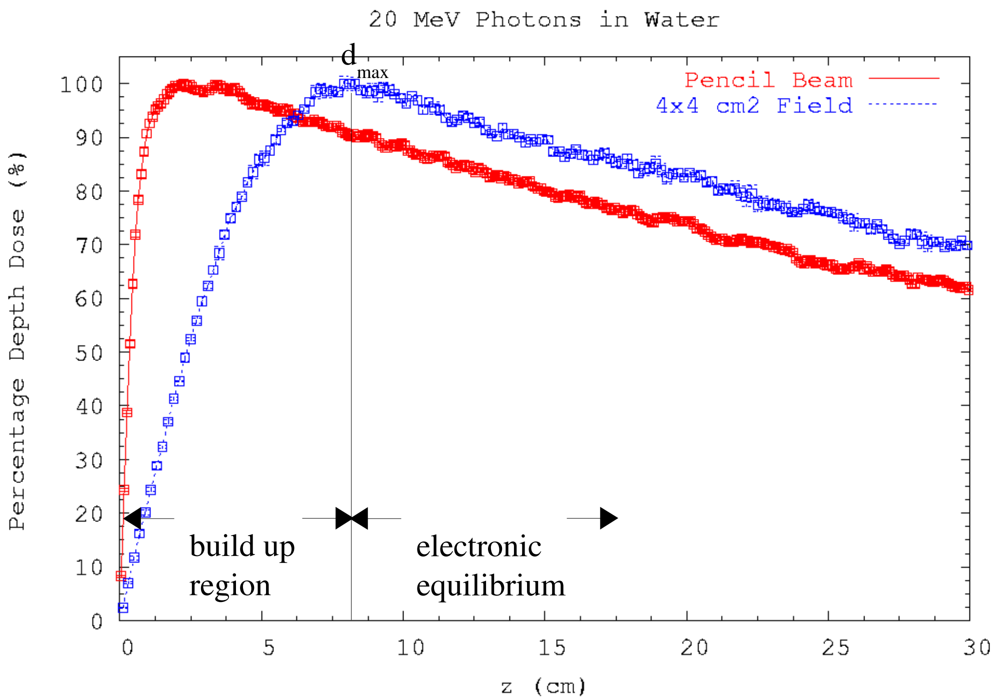


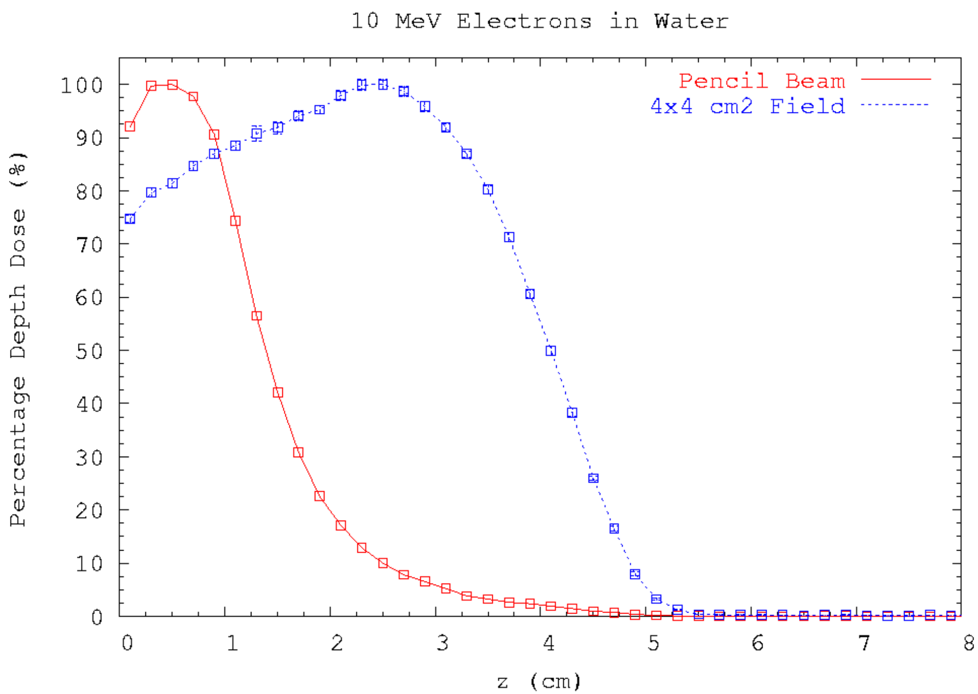
Electrons: 1 MeV 0.1x0.1x0.01 cm^3
10 batches of 2x10^5
10 MeV 0.2x0.2x0.2 cm^3
10 batches of 3x10^5
20 MeV 0.2x0.2x0.2 cm^3
10 batches of 10^5

Photons: 1 MeV 0.1x0.1x0.1 cm^3
10 batches of 2x10^6
10 MeV 0.2x0.2x0.2 cm^3
10 batches of 2x10^6
20 MeV 0.5x0.5x0.2 cm^3
4 batches of 2x10^6

	Pencil beam	$4x4\ cm^2$ field	Table values:
1 MeV	$d_{max} = 0.25$ cm $d_{50} = 10$ cm $\mu = (7.03\pm0.03)x10^{-2}$ 1/cm HVL = 9.85 ± 0.04 cm	$d_{max} = 1.2$ cm $d_{50} = 12.5$ cm $\mu = (6.11\pm0.06)x10^{-2}$ 1/cm HVL = 11.3 ± 0.1 cm	$\mu = 7.072x10^{-2}$ 1/cm HVL = 9.8 cm
10 MeV	$d_{max} = 1.5$ cm $d_{50} = 33$ cm $\mu = (2.195\pm0.006)x10^{-2}$ 1/cm HVL = 31.58 ± 0.09 cm	$d_{max} = 4.4$ cm $d_{50} = 39.3$ cm $\mu = (1.90\pm 0.04)x10^{-2}$ 1/cm HVL = 36.5 ± 0.7 cm	$\mu = 2.219x10^{-2}$ 1/cm HVL = 31.2 cm
20 MeV	$d_{max} = 2.25$ cm $d_{50} = 41$ cm $\mu = (1.793\pm0.005)x10^{-2}$ 1/cm HVL = 38.6 ± 0.1 cm	$d_{max} = 7.9$ cm $d_{50} = 49.9$ cm $\mu = (1.65\pm 0.01)x10^{-2}$ 1/cm HVL = 42.1 ± 0.2 cm	$\mu = 1.813x10^{-2}$ 1/cm HVL = 38.2 cm

Comparison between pencil beam and fields

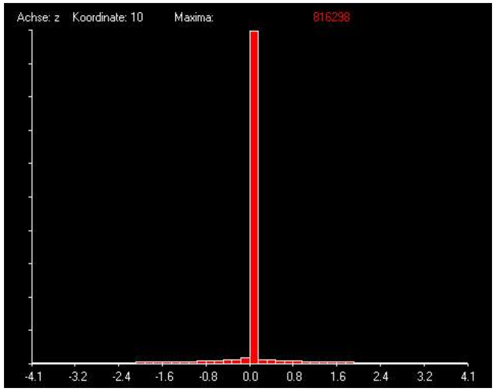


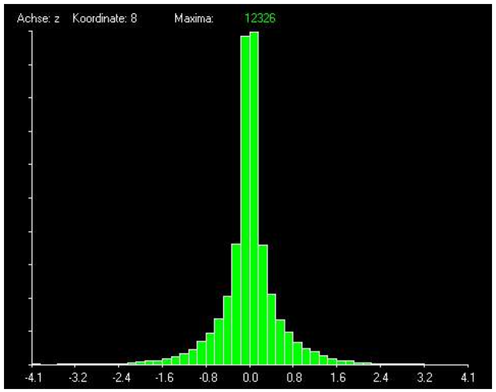


Remark: clinical photon beams are not mono energetic.

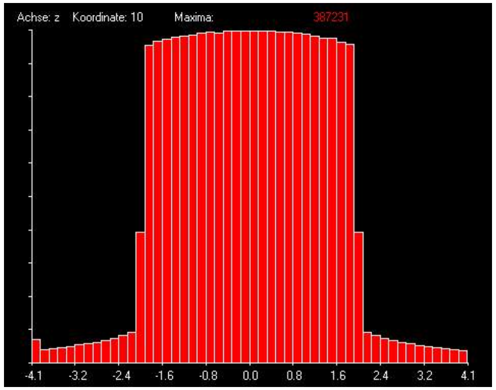
Profiles at 10 cm depth

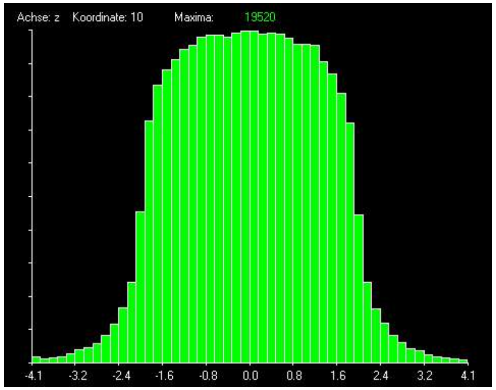
Pencil Beam





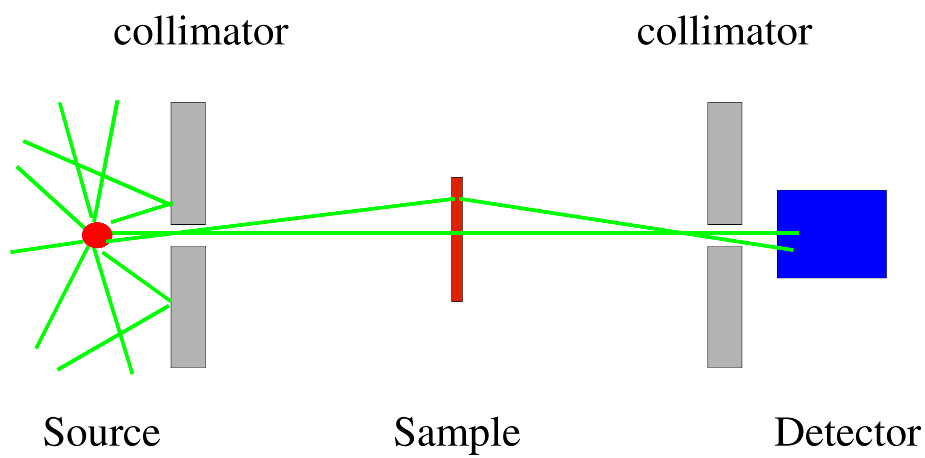
4x4 cm field





Photon attenuation

Good geometry (narrow beam)



Narrow collimation minimizes non-direct photons

Requires a very intense source or large measuring times

From $$dN = -\mu \, N \, dx$$

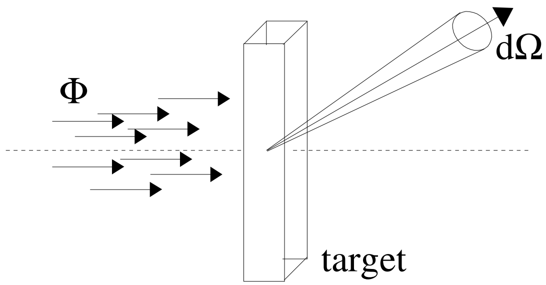
dN: reduction in the number of photons due to interactions in a thickness dx

$$N = N_o e^{-\mu x} = N_o e^{-(\mu/\rho)\,\rho\, x} \qquad N = N_o e^{-(\mu/\rho)\, t} \qquad t = \rho x \qquad [t] = g/cm^2$$

μ: linear attenuation coefficient (1/cm)

μ/ρ: mass absorption coefficient (cm^2/g)

Cross Section



$$N_s(\Omega) = \varphi S n_{tgt} \delta \frac{d\sigma}{d\Omega}$$

where $N_s(\Omega)$ is the average number of particles scattered into dΩ per unit time (1/s sterad),

φ is the number of incident particles per unit time and unit area or particle fluence rate (1/s m^2) ,

S is the total area of the target (m^2),

n_{tgt} is the number density of scattering centers (1/m^3),

δ is the thickness of the material along the beam direction (m),

$\frac{d\sigma}{d\Omega}$ is the differential cross section into the solid angle dΩ per unit time (m^2/sterad).

The total number of scattered particles into dΩper unit time is,

$$N_{tot} = \varphi S n_{tgt} \delta \sigma \qquad \sigma(E) = \int \frac{d\sigma}{d\Omega} d\Omega$$

where $d\Omega = 2\pi \sin\theta \, d\theta \, d\phi$.

σ gives a measure of the probability for a reaction to occur.

[σ] = m^2 1 barn = 10^{-28} m^2 = 10^{-24} cm^2

XCOM: Photon Cross Sections Database

http://physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html

Berger, Hubbell, et al.

Cross sections in barns (10^{-24} cm^2) per atom,

σ_{coh} coherent (Rayleigh) scattering:

Atomic form factor

$$\frac{d\sigma_{coh}}{d\Omega} = \frac{d\sigma_o}{d\Omega} F^2(q, Z) \qquad q \approx \frac{2E}{c} \sin(\theta/2)$$

Thomson scattering

σ_{inc} incoherent (Compton) scattering:

scattering function

$$\frac{d\sigma_{inc}}{d\Omega} = Z \frac{d\sigma_{KN}}{d\Omega} S(q, Z)$$

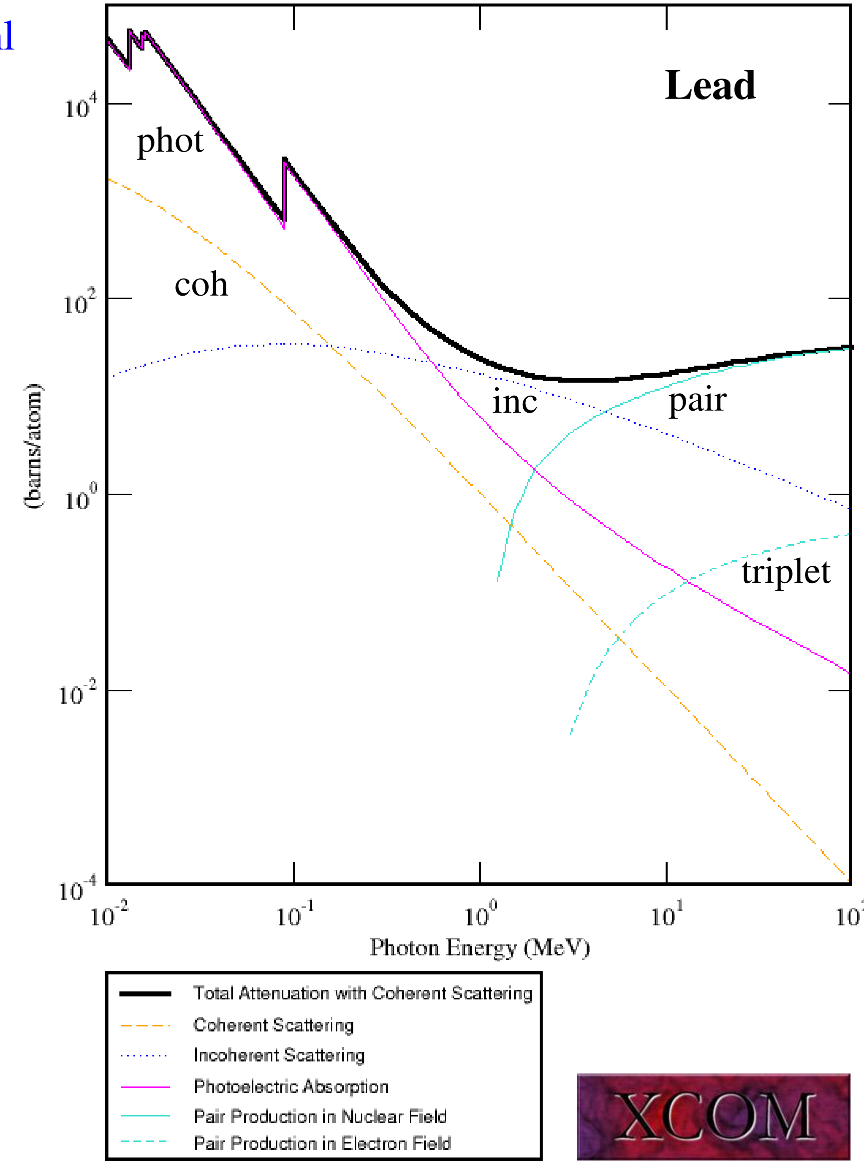
Klein-Nishina formula

$$\boxed{\sigma = \tau + \sigma_{coh} + \sigma_{inc} + \kappa_{pair} + \kappa_{trip}}$$

photoelectric

pair production

triplet production



XCOM

X-Ray Mass Attenuation Coefficients

http://physics.nist.gov/PhysRefData/XrayMassCoef/cover.html

based on calculations by J. H. Hubbell and S. M. Seltzer.

The number of scattering centers, N, for a simple element is,

$$N = \frac{N_a \rho}{A}$$

where ρ is the mass density (g/cm^3),
N_a is Avogadro's number = 6.022x10^{23} (1/mol),
A mass number (g/mol).

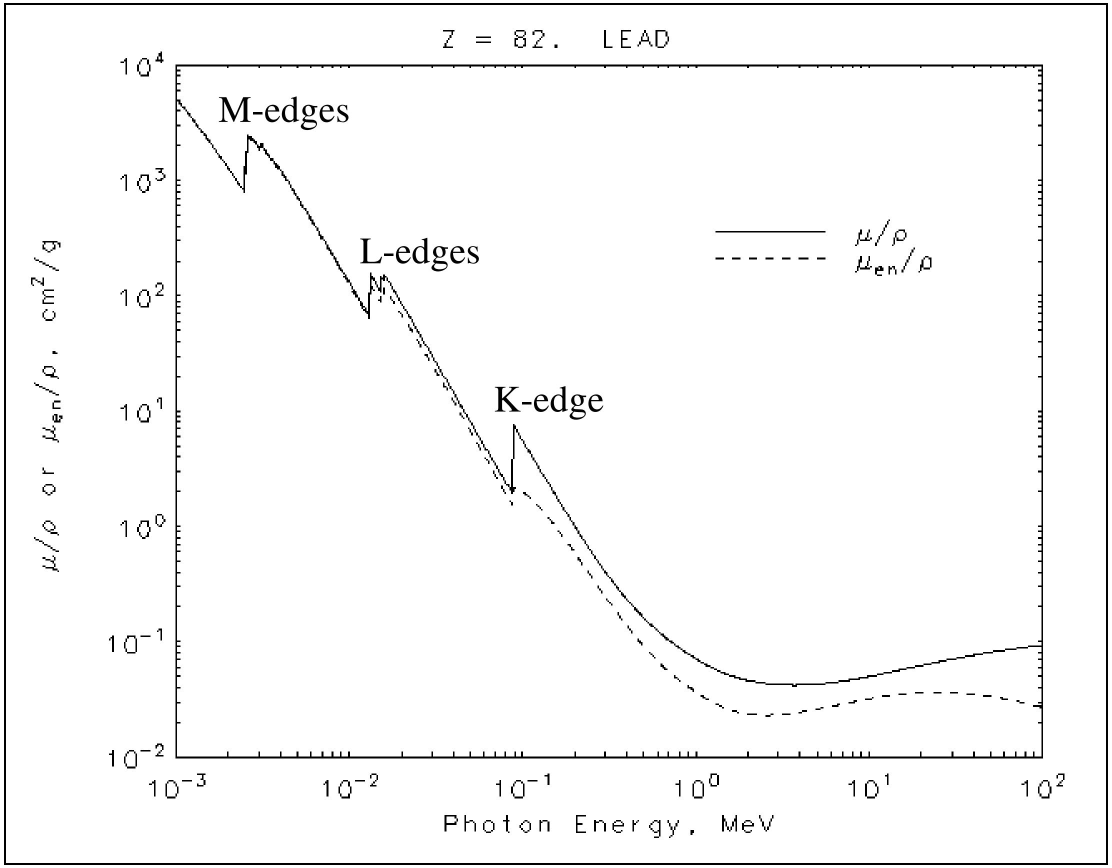
The linear attenuation coefficient (1/cm) is

$$\mu = N\sigma = \frac{N_a \rho}{A}\sigma$$

and the mass attenuation coefficient (cm^2/g),

$$\frac{\mu}{\rho} = \frac{N_a}{A}\sigma$$

$$\boxed{\frac{\mu}{\rho} = \frac{N_a}{A}\left(\tau + \sigma_{coh} + \sigma_{inc} + \kappa_{pair} \ldots\right)}$$



For compounds:

$$\frac{\mu}{\rho} = w_1 \frac{\mu_1}{\rho_1} + w_2 \frac{\mu_2}{\rho_2} + \ldots$$

w_i is the weight fraction of each element in the compound

EGS-Ray: attenuation of a homogenous photon beam

pencil beam (parallel geometry)

Geometry: Platte

A plane parallel to a given axis
(medium name
axis, 1st coordinate on this axis,
2nd coordinate on this axis).

Program control:

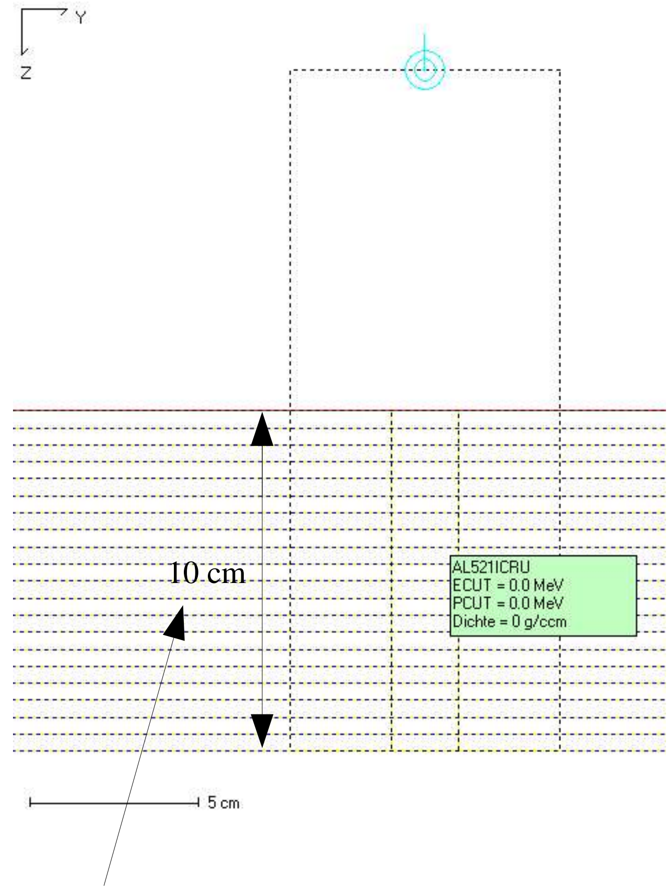
Generation

Only the doses of a determined generation (primary, secondary,etc) of particles is registered
(number of the generation to be summed)

Generation
1

adds the doses of only the first interacting particles, primary photons in this case. For more details look in the manual.

```
Daten
C:\EGSRay\Mediendaten\521icru.dat
Randomseed
1802 9373
Histories
100000
Punktquelle
0.  0.  0.
Richtung
0  0  1
Photonen
Energie
0.1
Rechenraum
-4  -4  0    4  4  20.
Scoringraum
-1  -1  10  1  1  20.
Voxelgrösse
2  2  0.1
Platte
AL521ICRU
2  10  20
Histogramm
2  10
Histogramm
2  10.25
.....
Histogramm
2  20
Generation
1
```



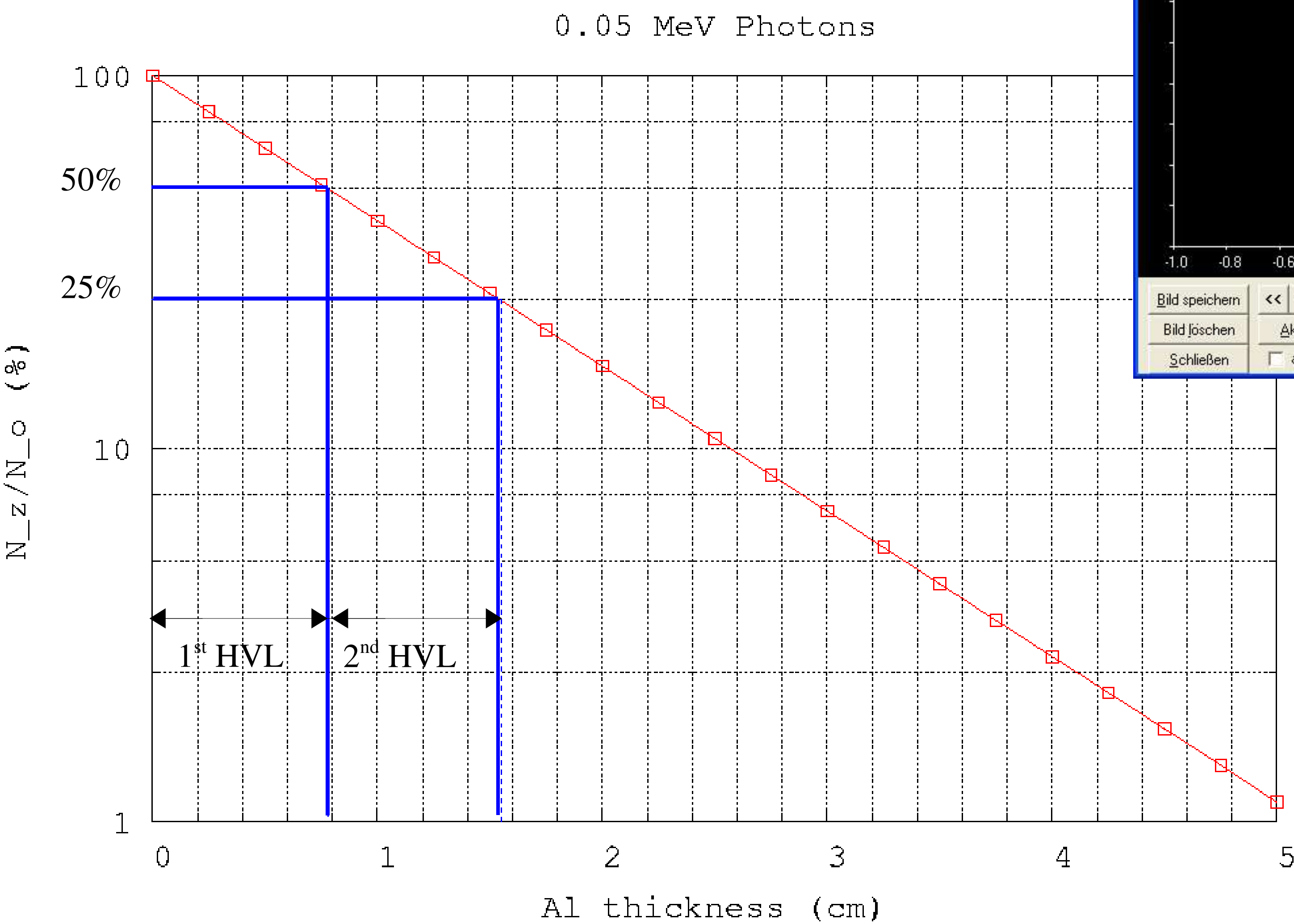
Suggested values:		
	0.05 MeV	5 cm
	0.1 Mev	10 cm
	1 MeV	20 cm
	10 MeV	30 cm

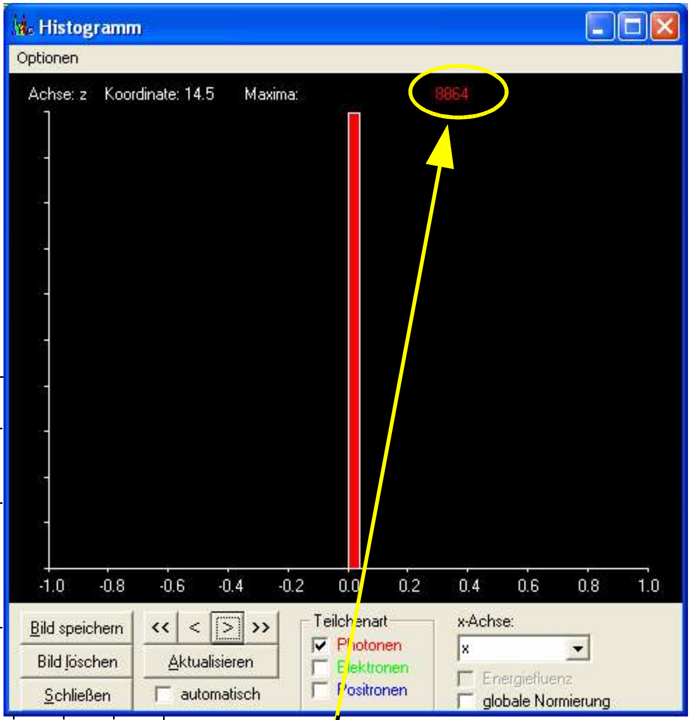
Half value layer of aluminum

Parallel photon beam
E = 0.05 MeV

Absorber material: Al

$$\text{Homogeneity grade} = \frac{1^{st}\ \text{HVL}}{2^{nd}\ \text{HVL}}$$





Photons on
the x axis at a given depth

Histogram analysis

Buildup effect behind a 0.35 mm Pb shield

divergent beam

Program control:

Richtungsbereich

Limits the direction of isotropically emitted particles.

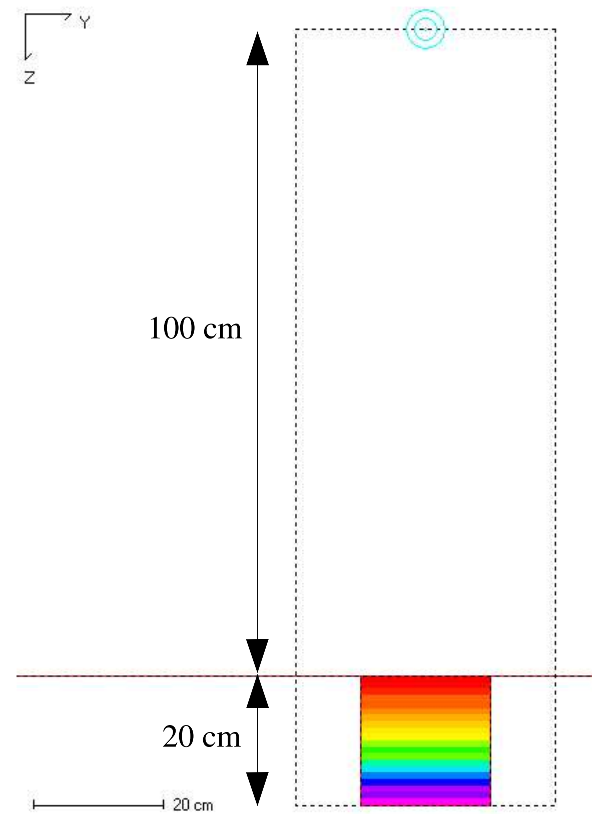
(Upper and lower limit to x direction cosine, upper and lower limit to y direction cosine, upper and lower limit to z direction cosine).

Geometry: Box

A parallelepiped

(x1,y1,z1 coordinates of 1 corner of a cube
x2,y2,z2 coordinates of opposing corner).

```
Daten
C:\EGSRay\Mediendaten\521icru.dat
Randomseed
1802 9373
Histories
100000
Punktquelle
0. 0. 0.
Richtungsbereich
-1  1   -1  1    0.995  1
Photonen
Energie
0.05
Rechenraum
-20 -20  0 20 20 120
Scoringraum
-15 -10 100  15 10  120.
Voxelgrösse
30 20 1
Platte
PB521ICRU
2  99.965  100
Box
H2O521ICRU
-15 -10 100.  15 10 120.
Presta
```



Assignment 03: attenuation of homogenous photon beams

Photon attenuation:

Simulate: parallel photon beams: E = 0.05, 0.1, 1, 10 MeV
Source to absorber distance: 10 cm
Absorber material: Al

Analysis: Determination of μ, 1st HVL, 2nd HVL, and homogeneity grade H for each case.

Pb shield:

Simulate: divergent photon beams: E = 0.05, 0.1, 1, 10 MeV
Source to phantom + Pb shield distance: 100 cm
Absorbers: Pb 0.035 cm
H_2O 20x20x30 cm^3

Analysis: Compare absorbed doses with and without Pb shield at several depths, 1 cm, 10 cm, and, 20 cm. Extract the relative ratios with Pb shield to without shield. Comment the results.

Scoring dimensions and voxel size adapted to each case. Enough statistics.