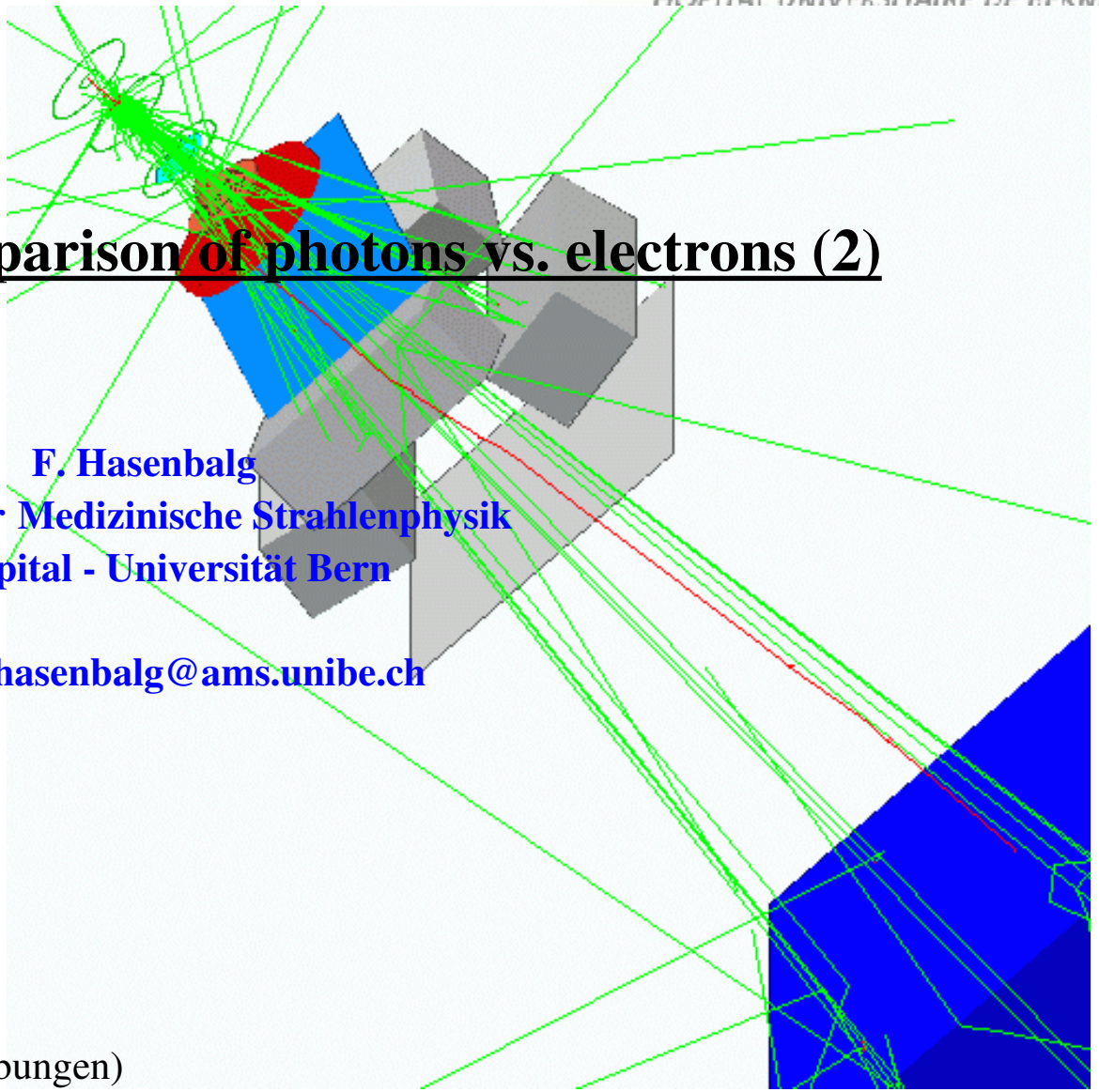
Abteilung für Medizinische Strahlenphysik
Inselspital, Universität Bern, Schweiz
www.ams.unibe.ch

INSELSPITAL
UNIVERSITÄTSSPITAL BERN
HOPITAL UNIVERSITAIRE DE BERNE

Pencil beam comparison of photons vs. electrons (2)

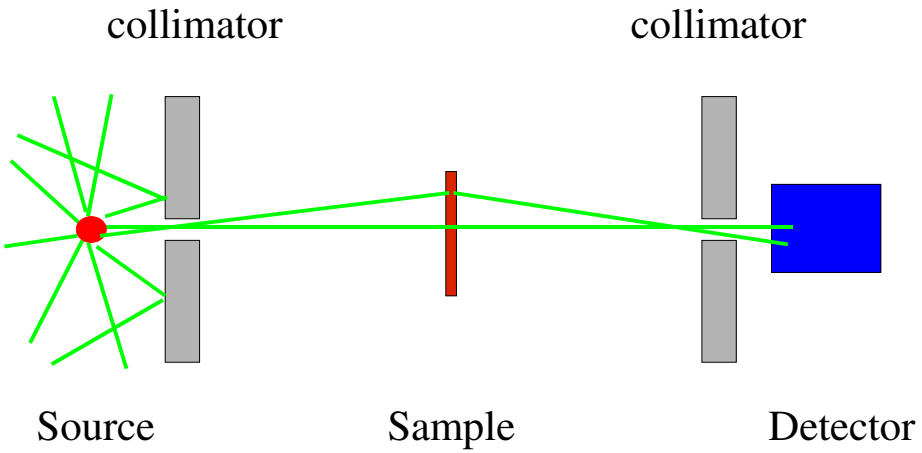


F. Hasenbalg
Abteilung für Medizinische Strahlenphysik
Inselspital - Universität Bern

e-mail: hasenbalg@ams.unibe.ch

Photon attenuation

Good geometry (narrow beam)



Narrow collimation minimizes non-direct photons

Requires a very intense source or large measuring times

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

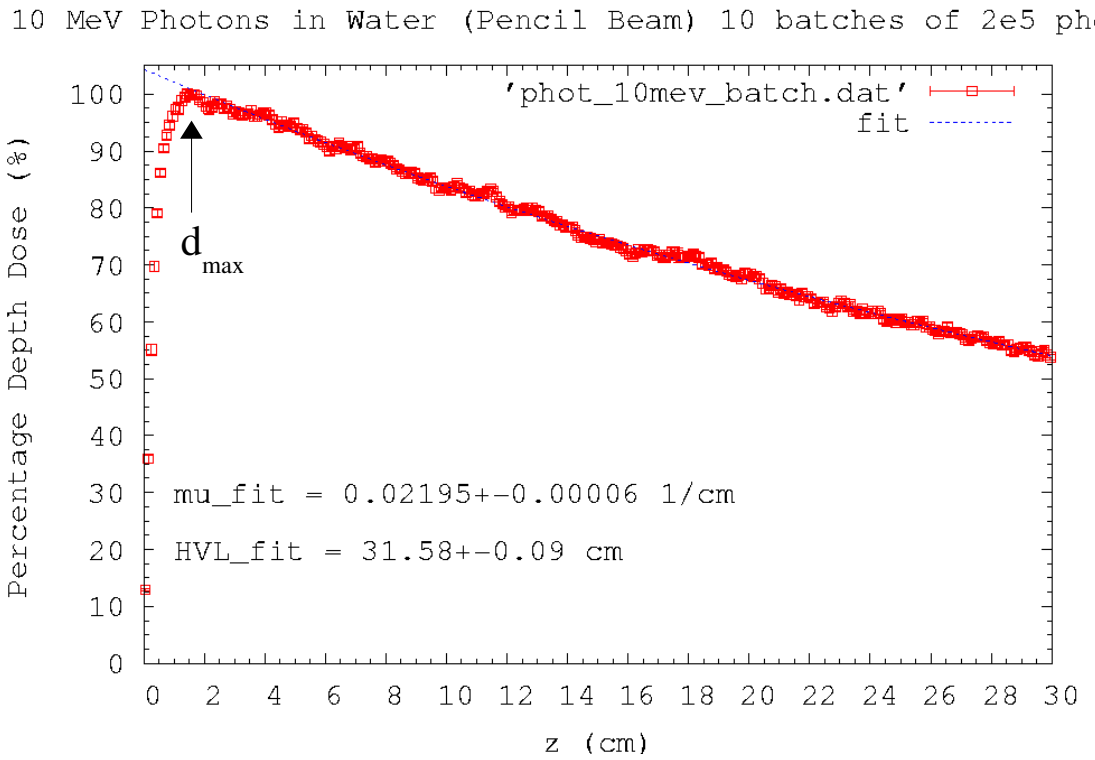
dN: reduction in the number of photons due to interactions in a thickness dx

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

μ: linear attenuation coefficient (1/cm)

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

Doing fits with gnuplot



Gnuplot commands to do a simple fit:

```
gnuplot> plot 'phot_10mev.dat' u 6:8:9 w errorb 1 3
gnuplot> a = 100
gnuplot> mu = 0.02
gnuplot> dmax = 2
gnuplot> y(x) = a*exp(-mu*(x-dmax))
gnuplot> fit [2.5:30] y(x) 'phot_10mev.dat' u 6:8:9 via a, mu, dmax
gnuplot> plot 'phot_10mev.dat' u 6:8:9 w errorb 1 3, y(x) w lin 3
gnuplot> save 'phot_10mev.plt'
```

initial parameters

function to fit

Goodness of fit:

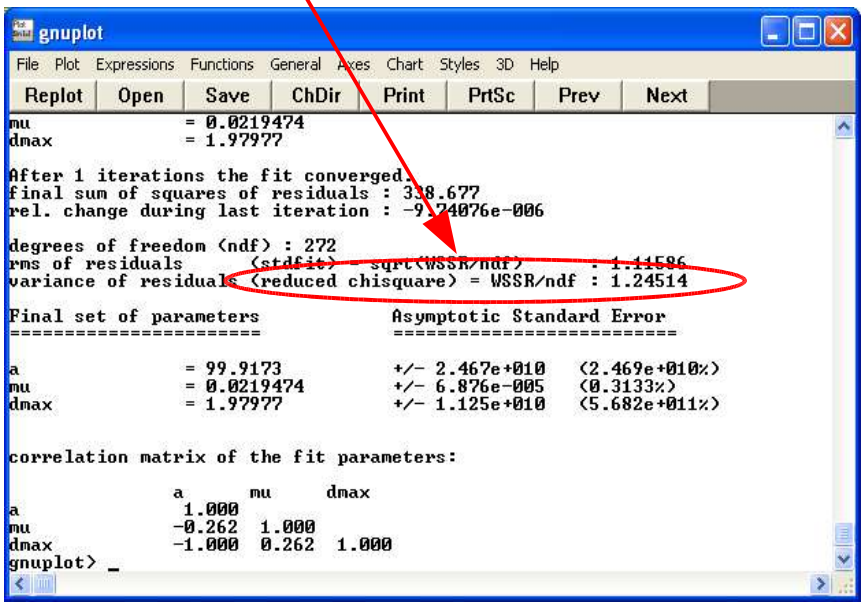
χ^2 distribution

obs : observed exp: expected

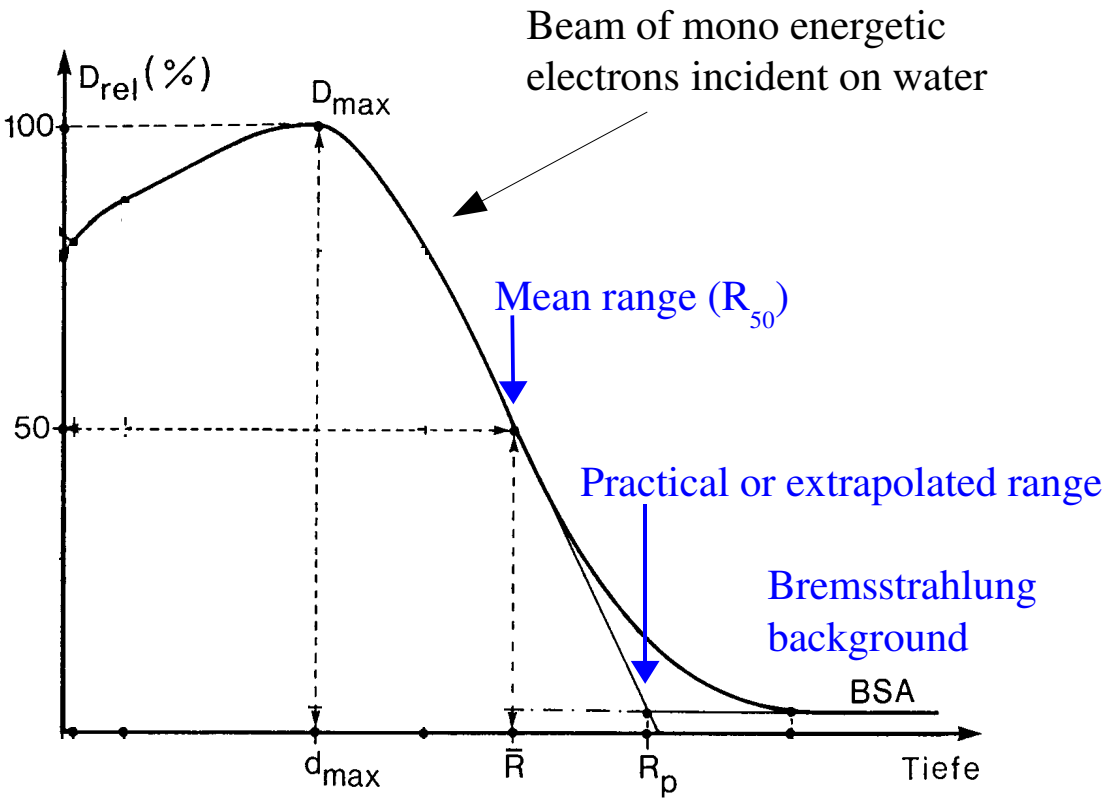
$$\chi^2 = \sum_{i=1}^{N} [y_{obs}(i) - y_{exp}(i)]^2 / \sigma_i^2$$

$$\approx \sum_{i=1}^{N} \sigma_i^2 / \sigma_i^2 = N$$

$$\chi^2_{red} \equiv \chi^2 / N_{d.o.f} \approx 1$$



Electron range: 10 MeV e⁻ in water



For e⁻ energies > 0.5 MeV:

$$R_p\ [cm] \approx E_o[MeV] / 2\rho\ [g/cm^3] \approx 5\ cm$$

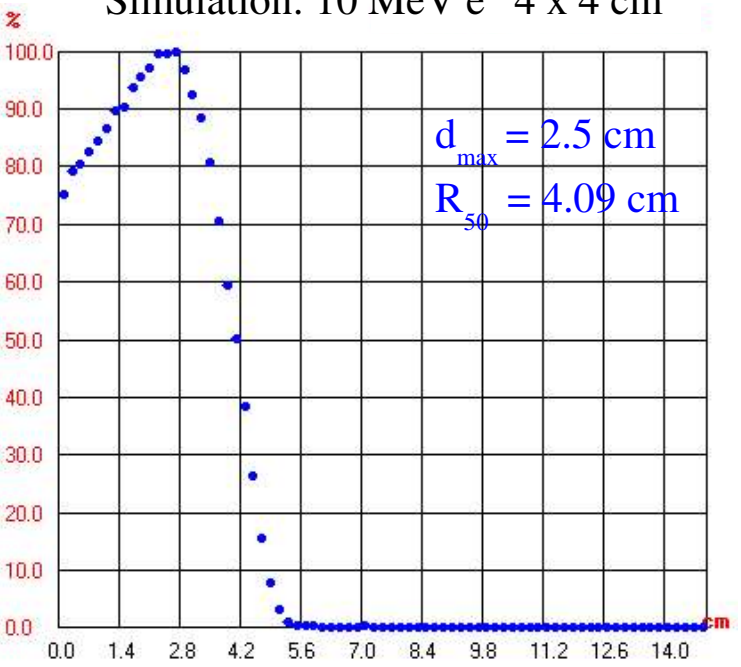
another approximation:

$$\bar{R} \approx E_o / S_{tot}(E_o) \approx 4.6\ cm$$

Better formula in water:

$$\bar{R}\ [cm] \approx E_o[MeV] / 2.33 \approx 4.3\ cm$$

Simulation: 10 MeV e⁻ 4 x 4 cm²



Continuous slow down approximation, CSDA:

$$R = \int_0^{Eo} dE / S_{tot}(E) \approx R_p \approx 4.975\ cm$$

$S_{tot}(E)$ stopping power = 2.149 MeV cm²/g

NIST ESTAR Stopping power and range tables for electrons

http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

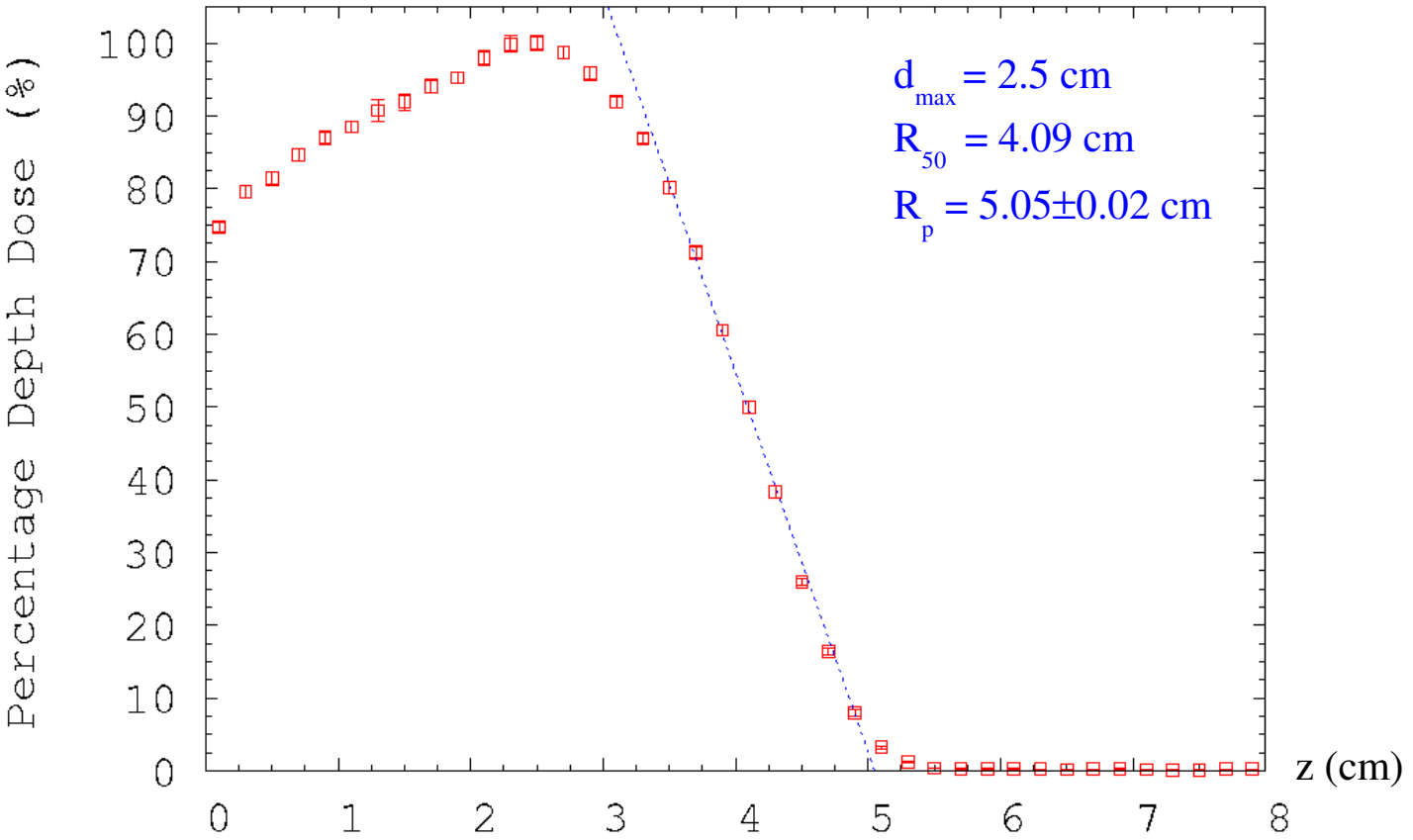
Electron range

Mono energetic beam of e$^-$

Beam energy: 10 MeV

Field size: 4x4 cm^2

Histories: 3x10^6



Gnuplot commands:

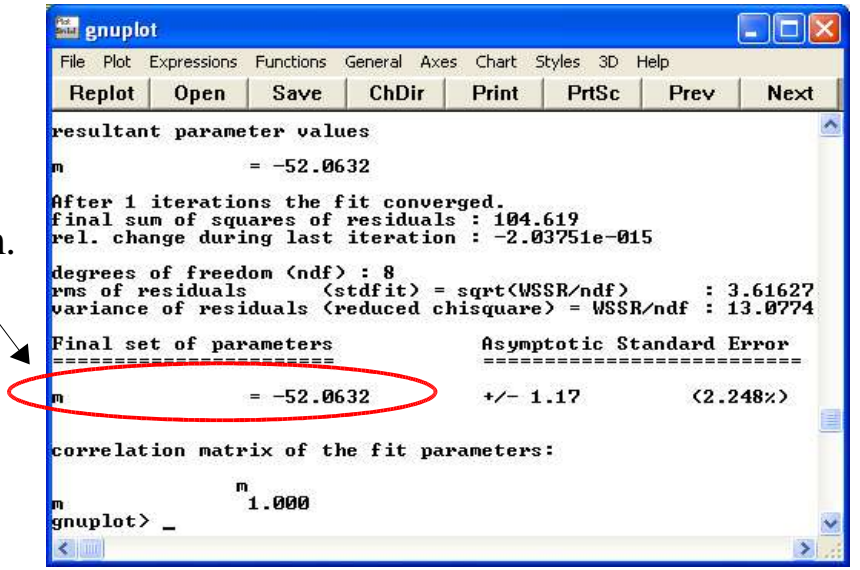
```
gnuplot> plot 'elec_10mev.dat' w errorb 1 3
gnuplot> m = - 40
gnuplot> b = 50
gnuplot> d50 = 4.09
gnuplot> y(x) = m*(x-d50) + b
gnuplot> fit [3.3:4.9] y(x) 'elec_10mev.dat' u 1:2:9 via m
gnuplot> plot 'elec_10mev.dat' w errorb 1 3, y(x) w lin
```

initial parameter

constants

function to fit

only 1 free param.



$$R_p\ [cm] = -50/m + d50$$

Material data

$^{108}_{47}Ag$

521icru.dat - Notepad

File Edit Format View Help

```
MEDIUM=AG521ICRU                ,STERNCID=AG521ICRU
 ELEM,RHO= 1.0500E+01,NE= 1,  IUNRST=0,  EPSTFL=1,  IAPRIM=1
 ASYM=AG,Z=47.,A=  107.870,PZ= 1.00000E+00,RHOZ= 1.07870E+02
    8.54380E-01   5.21000E-01   1.00000E-02   5.55110E+01   5.50000E+01
     0  200    0  150    0    0    0    0    0
    9.99979E-01  -2.42672E-01   5.56877E-02   9.95248E-01  -2.60478E-01
    9.52000E-01   1.00025E+00  -2.06110E-01   3.97343E-02   1.01634E+00
   -2.65997E-01   9.52000E-01   1.00040E+00  -1.87241E-01   2.87384E-02
    1.02722E+00  -2.68846E-01   9.52000E-01   9.99979E-01  -2.50696E-01
    5.75288E-02   9.95091E-01  -2.69089E-01   9.52000E-01   1.00026E+00
   -2.13074E-01   4.10768E-02   1.01689E+00  -2.74984E-01   9.52000E-01
    1.00041E+00  -1.93637E-01   2.97201E-02   1.02815E+00  -2.78030E-01
    9.52000E-01
    1.92575E+01   9.43781E-01   8.53227E-01   2.32072E+00   9.44443E-01
    8.53094E-01   2.04669E+00
    1.95523E-01   2.88570E-04   6.93205E+04   5.42582E+00
    8.11882E+01   1.71715E+01
    5.92440E+01   1.28625E+01   6.34367E+03   1.37663E+03  -2.02935E+02
   -6.60112E+01  -3.25729E+02  -9.61455E+01   1.00000E+00   0.00000E+00
    7.86213E-01   1.70696E-01   8.42337E+01   1.82881E+01   3.01100E-05
    5.81260E-06   5.92440E+01   1.28625E+01   6.34367E+03   1.37663E+03
   -2.02935E+02  -6.60112E+01  -3.25729E+02  -9.61455E+01   1.00000E+00
    0.00000E+00   7.86213E-01   1.70696E-01   8.42337E+01   1.82881E+01
    3.01100E-05   5.81260E-06   5.59969E+01   1.21494E+01   5.35484E+03
    1.15946E+03  -1.93724E+02  -6.39881E+01  -3.05697E+02  -9.17460E+01
    1.00000E+00   0.00000E+00   6.47095E-02   1.22413E-02   2.44550E+00
    3.26015E-01   3.27498E-05   6.39234E-06   5.14065E+01   1.11283E+01
    4.45548E+03   9.59391E+02  -1.84197E+02  -6.18689E+01  -2.85716E+02
   -8.73011E+01   1.00000E+00   0.00000E+00   5.12657E-02   9.25060E-03
    1.44431E+00   1.03287E-01   3.57647E-05   7.06304E-06   4.66957E+01
    1.00665E+01   3.68507E+03   7.85756E+02  -1.74976E+02  -5.97907E+01
   -2.66977E+02  -8.30778E+01   1.00000E+00   0.00000E+00   4.71457E-02
    8.32201E-03   1.20911E+00   5.02753E-02   3.90590E-05   7.80552E-06
    4.42603E+01   9.51033E+00   3.02779E+03   6.35646E+02  -1.65963E+02
   -5.77323E+01  -2.49294E+02  -7.90392E+01   1.00000E+00   0.00000E+00
    5.27771E-02   9.60813E-03   1.11801E+00   2.94717E-02   4.26529E-05
    8.62630E-06   4.01885E+01   8.56786E+00   2.46568E+03   5.05541E+02
   -1.57266E+02  -5.57192E+01  -2.32675E+02  -7.51927E+01   1.00000E+00
    0.00000E+00   5.11755E-02   9.23742E-03   1.07342E+00   1.91517E-02
    4.65758E-05   9.53427E-06   3.59469E+01   7.57270E+00   1.98661E+03
    3.93141E+02  -1.48888E+02  -5.37537E+01  -2.17092E+02  -7.15366E+01
    1.00000E+00   0.00000E+00   4.92369E-02   8.78257E-03   1.04838E+00
    1.32768E-02   5.08484E-05   1.05367E-05   3.43268E+01   7.18732E+00
    1.58298E+03   2.97130E+02  -1.40730E+02  -5.18131E+01  -2.02375E+02
```

PEGS4: generates all material data needed for the EGS code.
3 options: ELEM, COMP, MIX.
AE = 521 up to 55 MeV
AE = 700

AE: low energy threshold for the production of secondary knock-on electrons. Controls the statistical fluctuations in the energy loss.
Is a lower limit on ECUT.

AP: low energy threshold for the production of secondary brems-strahlung photons.

RHO: density (g/cm3).

PZ: relative number of atoms in the compound.

RHOZ: relative amount by weight of atoms in the mixture.

IUNRST: if 1, unrestricted collision stopping power is computed.

STERNCID: Sternheimer-Seltzer-Berger id for the density effect parameters.

EGS-Ray: a field example

Particle Sources: Feld
(x,y,z coordinates of
middle point of the field
Δx,Δy,Δz widths of field)

Program control:

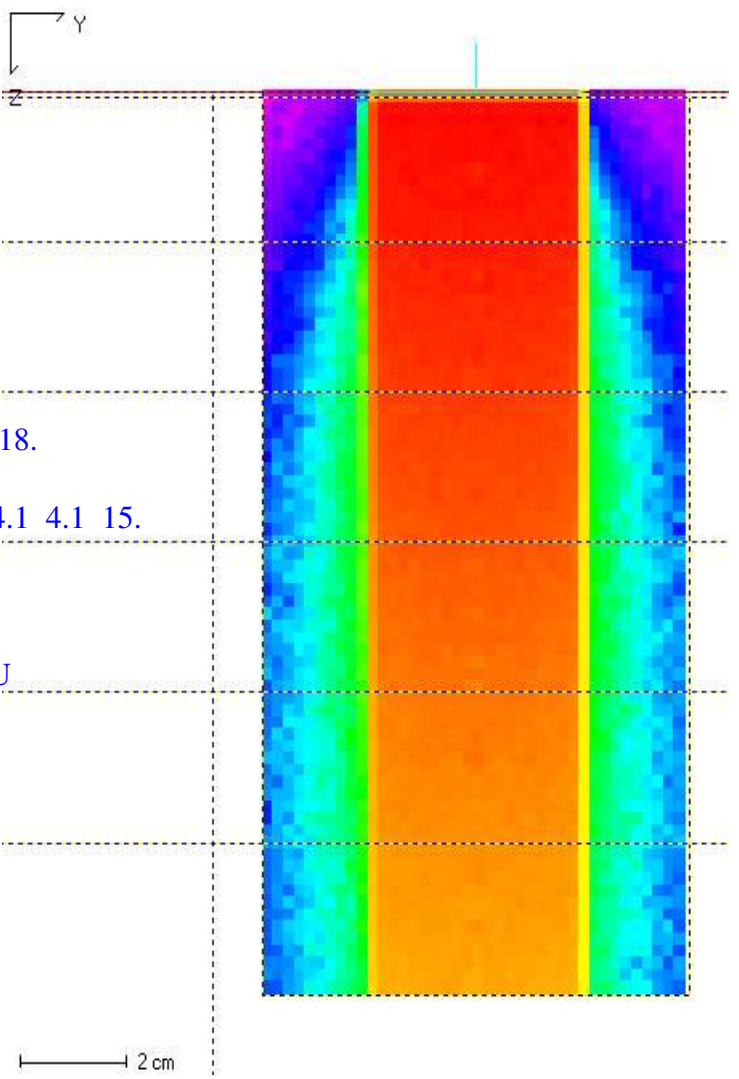
Histories
(number of particles to simulate
writes a *.sco scoring file at the end)

Batch
(number of batches to be done,
number of particles in each batch)
very useful to estimate errors of deposited
energy or doses

Script file for a simple 4x4 cm^2 field

```
Daten
C:\EGSRay\Mediendaten\521icru.dat
Randomseed
1802 9373
Feld
0.  0.  0.
4.0  4.0  0.0
Richtung
0  0  1
Photonen
Energie
1.0
Rechenraum
-5  -5  0  5  5 18.
Scoringraum
-4.1  -4.1  0  4.1  4.1  15.
Voxelgrösse
0.2 0.2 0.2
Halbraum
H2O521ICRU
2 0 1
Histogramm
2 0.1
.....
Histories
2000000
Presta
```

```
Batch
10
200000
```



Assignment 02: comparison between fields and pencil beams

Simulate: Photon 4 x 4 cm^2 fields E = 1, 10, 20 MeV
Electron 4 x 4 cm^2 fields E = 1, 10, 20 MeV
impinging on a water phantom
scoring dimensions and voxel size adapted to each case
enough statistics ($\approx 10^6$ particles)

Analysis: Photons: d_{max} and d_{50} from depth dose curves
qualitative description of the profiles at several depths

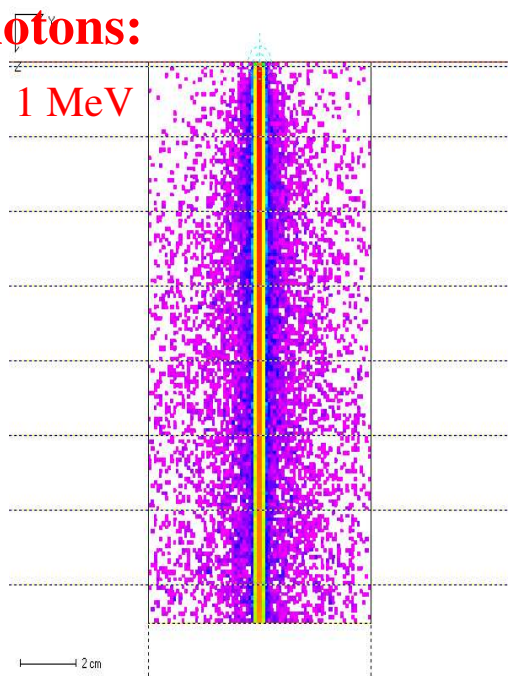
Electrons: d_{max}, R_{50}, R_p from depth dose curves
(compare R_p with R (CSDA) from the NIST ESTAR table)
qualitative description of the profiles at several depths

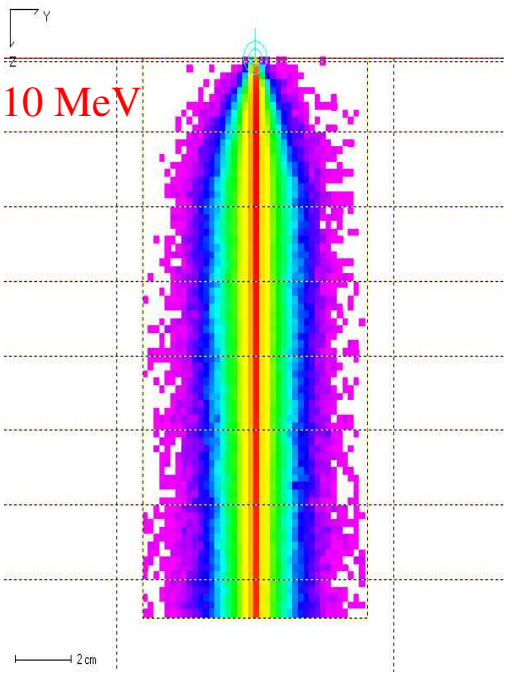
Briefly describe the qualitative differences between electrons and photons

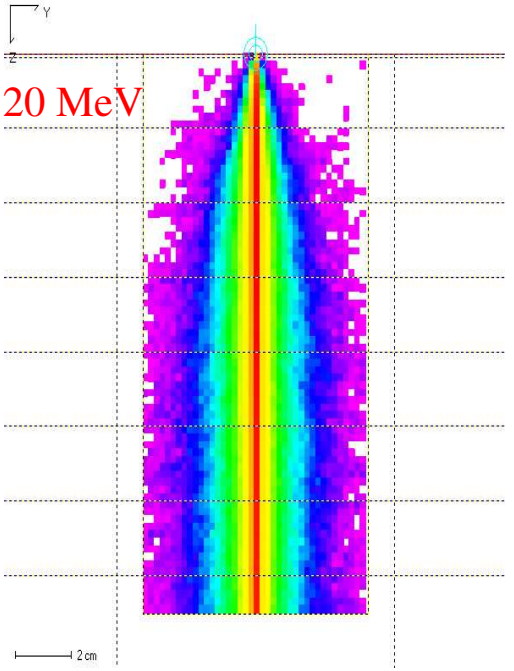
Describe the differences between pencil beams and fields for electrons and photons.

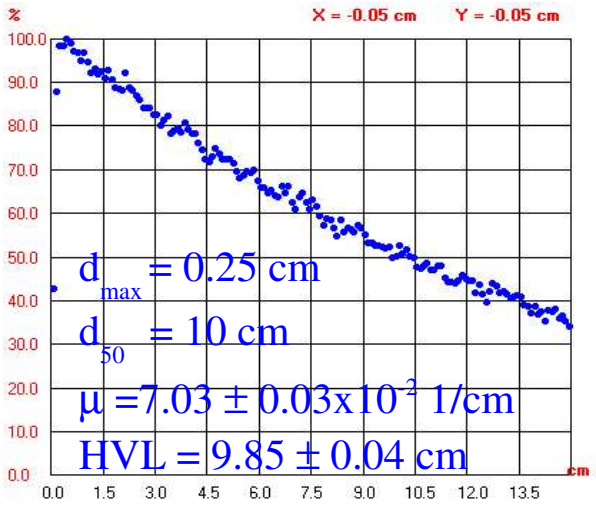
Results assignment 01: photon and electron pencil beams

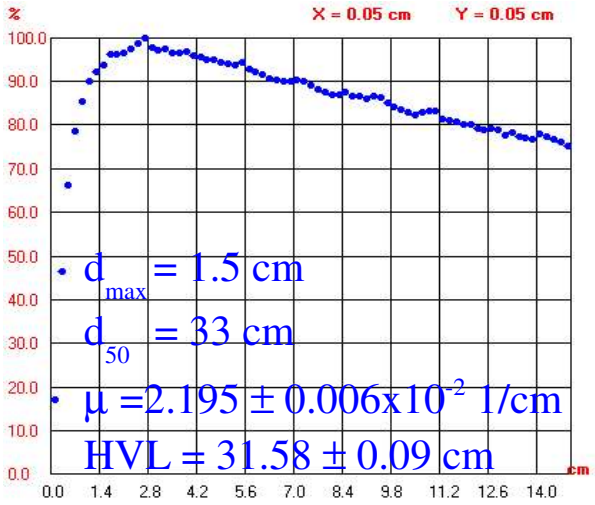
Photons:











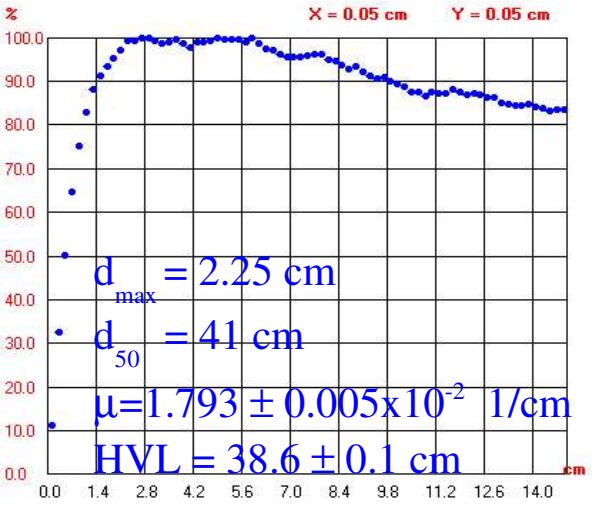


Table values: μ = 7.072x10^{-2} 1/cm
HVL = 9.8 cm

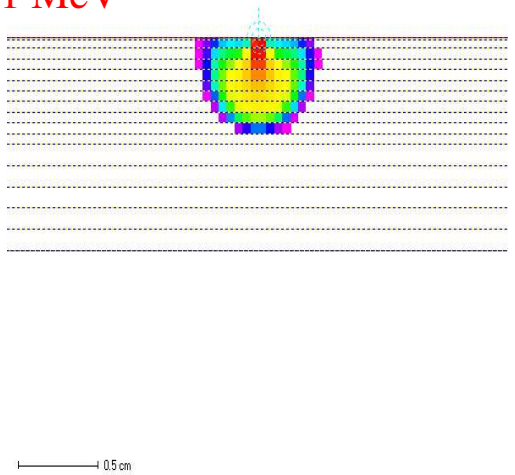
μ = 2.219x10^{-2} 1/cm
HVL = 31.2 cm

μ = 1.813x10^{-2} 1/cm
HVL = 38.2 cm

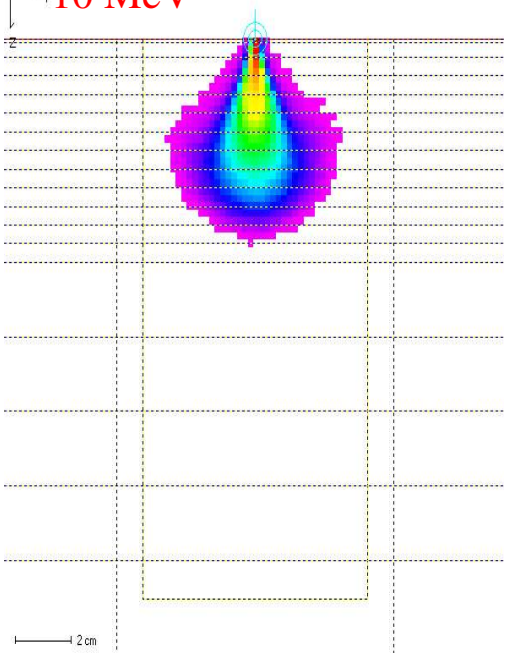
Results assignment 01: photon and electron pencil beams

Electrons:

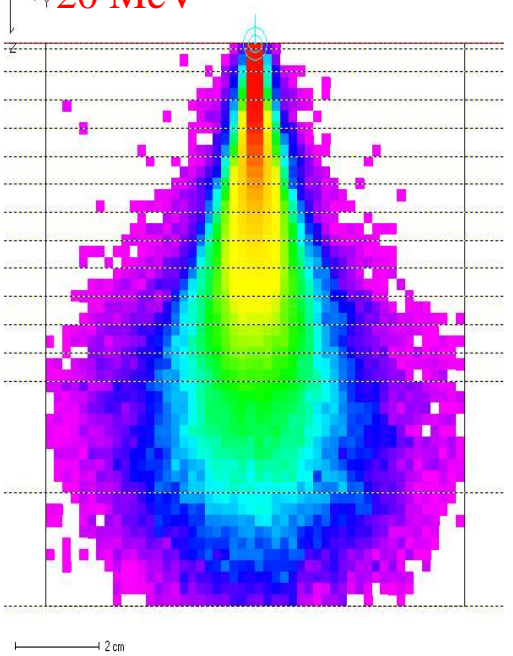
1 MeV

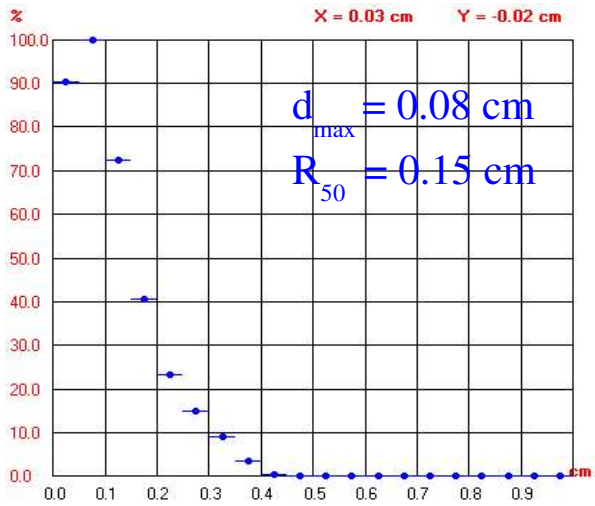


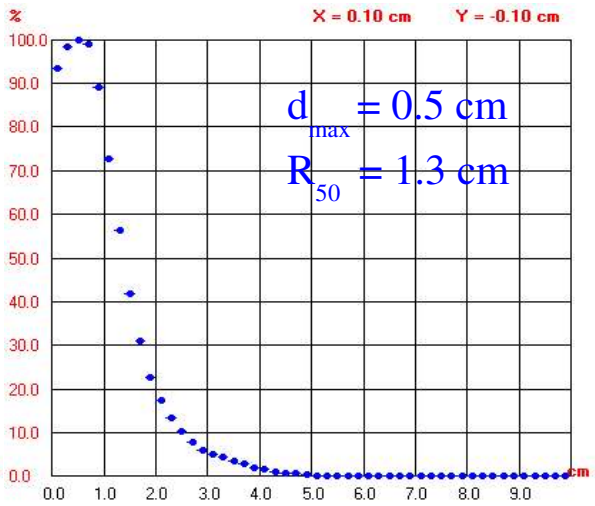
10 MeV



20 MeV







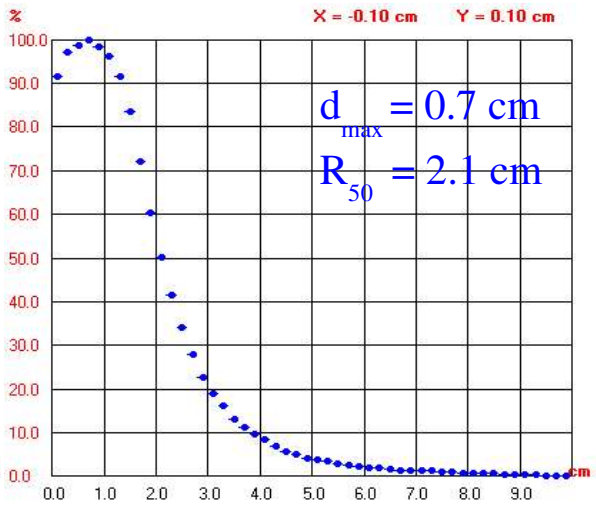


Table values: R_p = 0.44 cm R_p = 4.97 cm R_p = 9.32 cm