Topas Monte-Carlo modelling: Guide and simple techniques

Claus E. Andersen
Technical University of Denmark
Department of Health Technology
clan@dtu.dk
www.mrdc.dtu.dk

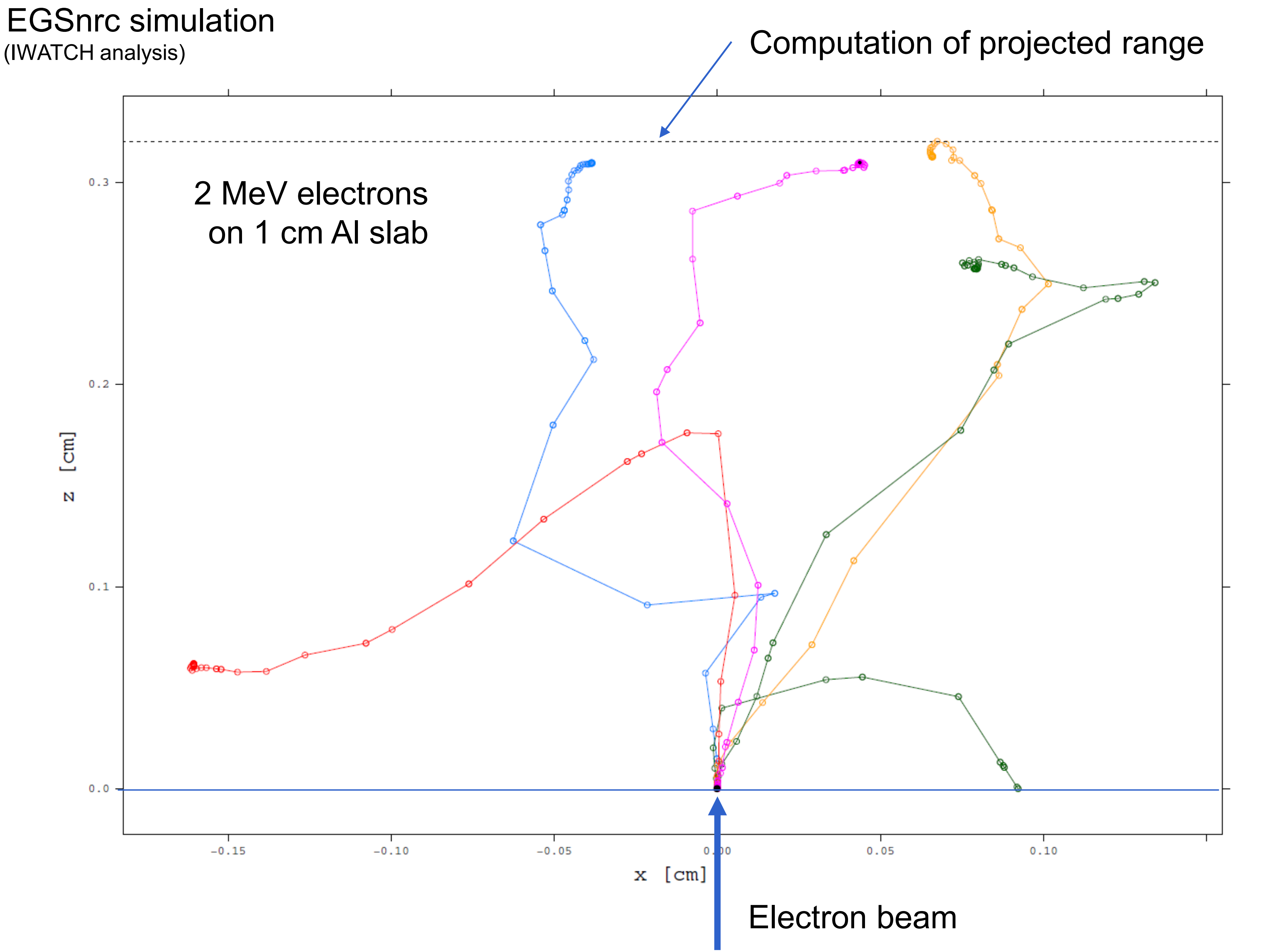
Created: January 3, 2023
Revised: January 25, 2023

DTU Health Tech

IMPORTANT

Topas is a research tool.

It cannot be used directly for clinical work.


EGSnrc simulation
(IWATCH analysis)
Computation of projected range
2 MeV electrons
on 1 cm Al slab
z [cm]
x [cm]
0.0
0.1
0.2
0.3
−0.15
−0.10
−0.05
0.00
0.05
0.10
Electron beam

What types of sections do we have in Topas parameter files?

Topas Documentation, Release 3.8 by Topas MC Inc :

8.6.5 Quick Ways to Deactivate Parts of the Parameters Files

For most parameter categories, there is one key kind of parameter that triggers creation:

Parameter object type	Triggering pattern
Element	El/.../Symbol =
Material	Ma/.../Components =
Component	Ge/.../Parent =
Particle Source	So/.../Type =
Physics setup	Ph/.../Type =
Scorer	Sc/.../Quantity =
Graphic	Gr/.../Type =
Variance Reduction	Vr/.../Type =
Time Feature	Tf/.../Function =

How to refer to particle types in Topas?

Particle names used in parameter files
(e.g. for particle sources or filters)

```
gamma
e-
e+
neutron
proton
...
```

Main particle codes used in output
(defined by the Particle Data Group, PDG)

```
22   = photon
11   = electron
-11  = positron
2112 = neutron
2212 = proton
...
```

What processes do Topas know about?

What physics is applied?

Selection of physics lists

1. The default, built-in physics list is :

```
sv:Ph/Default/Modules 6 g4em-standard_opt4 g4h-phy_QGSP_BIC_HP
g4decay g4ion-binarycascade g4h-elastic_HP g4stopping
```

This is what you get if, you do not specify anything.

2. Just electromagnetic interactions:

```
s:Ph/ListName = ”MyList"
sv:Ph/MyList/Modules = 1 "g4em-standard_opt4”
```

To obtain extra accuracy, one can specify that even very low-energetic electrons should be produced and transported. The energy cut is specified as a range in the local material. For example:

```
d:Ph/MyList/CutForElectron = 0.001 mm   # High accuracy

d:Ph/MyList/CutForElectron = 10 mm      # Low accuracy
```

3. Hadronics, radioactive decay etc. :

```
s:Ph/ListName = ”MyList2"
sv:Ph/MyList2/Modules = 7 "g4em-standard_opt4"
"g4h-phy_QGSP_BIC_HP" "g4decay" "g4ion-binarycascade"
"g4h-elastic_HP" "g4stopping" "g4radioactivedecay”
```

Process names (examples)

These names can, e.g., be used by filters to score particles from processes.

Name	Description
`"annihil”`	Annihilation
`"compt"`	Compton
`"eBrem"`	Bremsstrahlung produced by electron
`"Decay"`	Decay (of sub-atomic particle)
`"eIoni"`	
`"hadElastic"`	Hadronic elastic scattering
`"hIoni”`	
`"neutronInelastic"`	
`"nCapture"`	Neutron capture
`”phot"`	Photoelectric effect
`"primary"`	
`"protonInelastic”`	
`”RadioactiveDecayBase”`	Radiation from radioactive decay
`”Rayl”`	Rayleigh scattering (photons)

To see what processes you have use:
b:Ph/ListProcesses = "TRUE” and b:Ts/DumpParameters = "True"

Registered Physics Processes for "g4em-standard_opt4”:
Transportation, StepLimiter, UserSpecialCut, phot, compt, conv, Rayl, msc, eIoni, eBrem, ePairProd, CoulombScat, annihil, muIoni, muBrems, muPairProd, hIoni, hBrems, hPairProd, ionIoni, nuclearStopping

Registered Physics Processes for the default built-in physics list (6 modules):
Transportation, StepLimiter, UserSpecialCut, phot, compt, conv, Rayl, msc, eIoni, eBrem, ePairProd, CoulombScat, annihil, muIoni, muBrems, muPairProd, hIoni, hBrems, hPairProd, ionIoni, nuclearStopping, neutronInelastic, nCapture, nFission, protonInelastic, pi+Inelastic, pi-Inelastic, kaon+Inelastic, kaon-Inelastic, kaon0LInelastic, kaon0SInelastic, lambdaInelasticanti-lambdaInelastic, sigma-Inelastic, anti_sigma-Inelastic, sigma+Inelasticanti_sigma+Inelastic, xi-Inelastic, anti_xi-Inelastic, xi0Inelastic, anti_xi0Inelastic, omega-Inelastic, anti_omegaInelastic, anti_protonInelastic, anti_neutronInelastic, anti_deuteronInelastic, anti_tritonInelastic, anti_He3Inelastic anti_alphaInelastic, Decay, dInelastic, tInelastic, He3Inelastic, alphaInelastic, ionInelastic, hadElastichFritiofCaptureAtRest, hBertiniCaptureAtRest, muMinusCaptureAtRest

How to estimate the ”statistical” uncertainty of a result?

Examples of what we can request Topas to report

Statistics for a scorer

sv:Sc/MyScorer/Report = 1 “Sum”
sv:Sc/MyScorer/Report = 4 “Count_In_Bin” “Sum” “Mean” “Standard_Deviation”

Histories, Count_In_Bin,
Sum, Mean,
Variance, Standard_Deviation,
Second_Moment,
Min, Max

Histories = total number of histories (N) that were simulated
Count_In_Bin = number of histories that contributed to the bin
(i.e. excluding histories for which no particles hit this bin).

If we call

Standard_Deviation = SD

then

u(mean) = SD/sqrt(N) = the statistical uncertainty of the mean value
u(sum) = u(mean * N) = u(mean) * N = SD/sqrt(N) * N = SD * sqrt(N)

Sample output and uncertainty statement

```
# TOPAS Version: 3.7
# Parameter File: sandbox-10011.txt
# Results for scorer clanScorer1
# Scored in component: centerrod
# X in 1 bin  of 1 cm
# Y in 1 bin  of 1 cm
# Z in 200 bins of 0.15 cm
# DoseToMedium ( Gy ) : Count_in_Bin   Sum   Mean   Standard_Deviation
0, 0, 0, 429, 1.478240250207818e-07, 1.478240269572828e-13, 9.802415598904964e-12
0, 0, 1, 403, 1.445507535891011e-07, 1.445507558951234e-13, 9.149940147400391e-12
..
0, 0, 5, 444, 1.635282558254403e-07, 1.635282491183899e-13, 1.000433808080876e-11
0, 0, 6, 449, 1.670288014565813e-07, 1.670288067970067e-13, 1.056387068426724e-11
```

N = 1000'000 histories

Sum Mean Standard deviation

So, assume the mean dose for the z=6 voxel is our key result. What is the statistical uncertainty?

D = 1.670288067970067e-13 Gy

u(D) = 1.056387068426724e-11 Gy/sqrt(N) = 1.1 E-14 Gy

So, we could write: **D = (1.67 +/- 0.11) E-13 Gy (k=1)**

The uncertainty u(D) tells us how well we think we know the result D.
The "k = 1" implies that the uncertaity is a standard uncertainy (i.e. expressed as one standard deviation).

Can I have more than one scorer in a file?

”Multiple scorers” mean ”multiple files”

No, there can only be one scorer per output file.

It may therefore be useful to let the names of output files consist of two parts:
(1) a first part common for the given parameter file, and (2) a second part which is specific for each scorer.

One can realize the ”common part” by using the ”message parameter” as shown below:

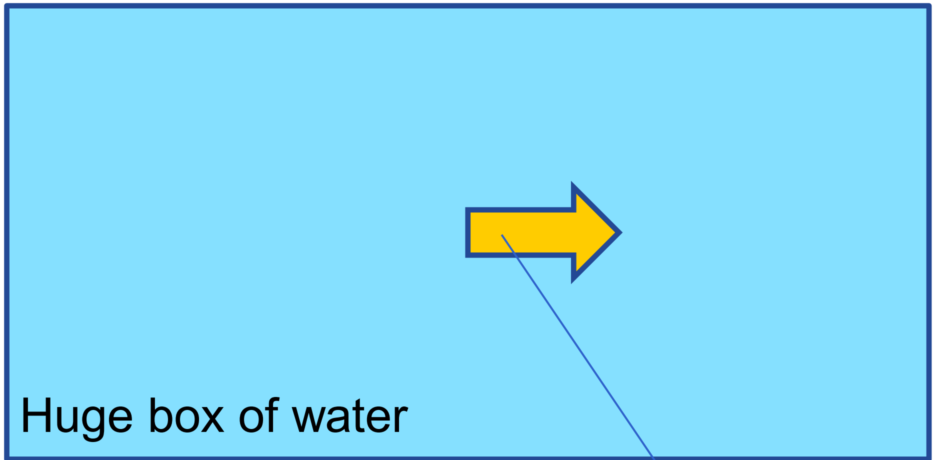
```
s:Ge/World/Message = "flatpanel-10002-”
s:Sc/clanScorer1/OutputFile = Ge/World/Message + "DoseScorer1"
s:Sc/clanScorer2/OutputFile = Ge/World/Message + "DoseScorer2"
s:Sc/clanScorer3/OutputFile = Ge/World/Message + "Phasespace1“
```

which produces output files:

```
flatpanel-10002-DoseScorer1
flatpanel-10002-DoseScorer2
flatpanel-10002-Phasespace1
```

Can Topas measure dose?
Let’s make a simple test.

Test of dose-to-medium scorer



All particle energy stays within the huge box of water, so we know the mean dose!

Internal source of 1 MeV particles emitted in the z-direction

Box of water.
Dimensions = 10 m x 10 m x 100 m of water with density 1 g/cm^3

Score the dose in the box: Energy imparted divided by mass of box

Send off N = 80000 1 MeV particles. What will the mean dose in the box be if we assume that no primaries and secondaries escape the box?

$$D = \frac{80000 \cdot 10^6 \cdot 1.60217649 \cdot 10^{-19}\mathrm{J}}{10 \cdot 10 \cdot 100\ \mathrm{m}^3 \cdot 10^3\ \mathrm{kg/m}^3}$$

$$D = 1.28174119 \cdot 10^{-15}\ \mathrm{Gy}$$

$$\rho = 1\,\frac{\mathrm{g}}{\mathrm{cm}^3} = 10^3\,\frac{\mathrm{kg}}{\mathrm{m}^3}$$

Test of dose-to-medium scorer

```
# The slab 1
s:Ge/clanSlab1/Type     = "TsBox”
s:Ge/clanSlab1/Material = "Water_75eV”
s:Ge/clanSlab1/Parent   = "World”
d:Ge/clanSlab1/HLX      = 5 m
d:Ge/clanSlab1/HLY      = 5 m
d:Ge/clanSlab1/HLZ      = 50 m
d:Ge/clanSlab1/TransX   = 0. m
d:Ge/clanSlab1/TransY   = 0. m
d:Ge/clanSlab1/TransZ   = 0. mm
d:Ge/clanSlab1/RotX     = 0. deg
d:Ge/clanSlab1/RotY     = 0. deg
d:Ge/clanSlab1/RotZ     = 0. deg
```

Test of dose-to-medium scorer

```
# Beam position
s:Ge/clanBeamPosition/Parent = "clanslab1"
s:Ge/clanBeamPosition/Type = "Group"
d:Ge/clanBeamPosition/TransX = 0.0 m
d:Ge/clanBeamPosition/TransY = 0.0 m
d:Ge/clanBeamPosition/TransZ = 0.0 m
d:Ge/clanBeamPosition/RotX = 0.0 deg
d:Ge/clanBeamPosition/RotY = 0.0 deg
d:Ge/clanBeamPosition/RotZ = 0.0 deg

# Beam
s:So/clanBeam/Type                 = "Beam"
s:So/clanBeam/Component            = "clanBeamPosition"
s:So/clanBeam/BeamParticle         = "e-"
d:So/clanBeam/BeamEnergy           =  1 MeV
```

Particle	Energy	Dose [10^{-15} Gy]	Method
Anything	1 MeV	1.28174119 (hand computation)	Analytical (reference)
e-	1 MeV	1.28174116	Topas, OK
gamma	1 MeV	1.28174116	Topas, OK
proton	1 MeV	1.28174116	Topas, OK
neutron	1 MeV	4.13712127	Topas, OK?
neutron	1 eV	2.8540072	Topas
neutron	1 MeV – 1 eV	1.28311	Difference (probably ok)

Test of dose-to-medium scorer

Why did the test apparently fail for neutrons?

Topas measured a dose exceeding 2 MeV per particle even when the neutrons only had 1 eV kinetic energy! This must somehow be related to rest mass changes.

The difference between the dose from 1 eV neutrons and 1 MeV neutrons is about 1 MeV. This indicates that the excess energy is released by a process occuring already at thermal neutron energies.

Further investigation using the 4pi-detector (see later) reveals that thermal neutrons undergo **neutron capture with the emission of a prompt 2.22 MeV gamma**. We transform hydrogen to deuterium, and get heavy water! This explains the excess energy absorption. Deuterium is a stable isotope, so there is no activation. We do not get exactly 2.22 MeV in the computation as activation of oxygen can also happen (see next slide), albeit only with a low probability.

<u>What else to consider with neutron modelling?</u>

We need a physics list that handles hadronics. The Topas 3.9 default physics lists were used for these computations. If the physics list had been set to `g4em-standard_opt4` (only electromagnetic interactions = em), for example, Topas would not have known how to transport neutrons and the neutron kinetic energy would be dumped on the spot.

Test of dose-to-medium scorer

Neutron activation of water?

Progress in Nuclear Energy 117 (2019) 103042

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Review

On the dose fields due to activated cooling water in nuclear facilities

Andrej Žohar, Luka Snoj*

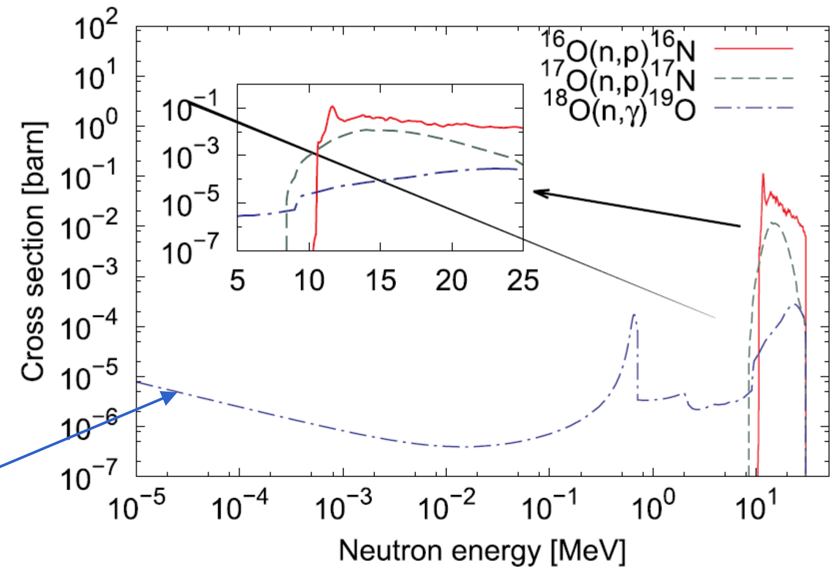


Fig. 1. Cross-section energy dependence for activation of oxygen nuclide taken from the JEFF-3.2 data library (OECD/NEA Data Bank, 2014).

Note that the O-18 reactions are possible at thermal neutron energies

... but it is not very likely

Isotope	Natural abundance [%]	Reaction	Activation product	$t_{1/2}$ [s]	Decay products
^{16}O	99.76	(n,p)	^{16}N	7.13	2.742 MeV gamma (1 %) 6.129 MeV gamma (67 %) 7.115 MeV gamma (5 %)
^{17}O	0.04	(n,p)	^{17}N	4.14	0.383 MeV neutron (35 %) 0.884 MeV neutron (1 %) 1.171 MeV neutron (53 %) 1.700 MeV neutron (7 %)
^{18}O	0.04	(n,γ)	^{19}O	26.9	0.110 MeV gamma (3 %) 0.197 MeV gamma (63 %) 1.357 MeV gamma (33 %) 1.444 MeV gamma (3 %)

How to apply filters to get results for certain particles etc. ?

or

How to find μ for mono-energetic photon beams?

or

What is a primary photon in Topas?

Filters for scorers

```
sv:Sc/FS6/OnlyIncludeParticlesNamed = 1 "gamma”

d:Sc/FS6/OnlyIncludeIfIncidentParticleKEAbove = 9.95 MeV

s:Sc/FS6/OnlyIncludeParticlesOfGeneration = "Primary”

s:Sc/FS6/OnlyIncludeParticlesOfGeneration = "Secondary”

sv:Sc/FS6/OnlyIncludeIfParticleOrAncestorFromProcess = 1 "compt"
```

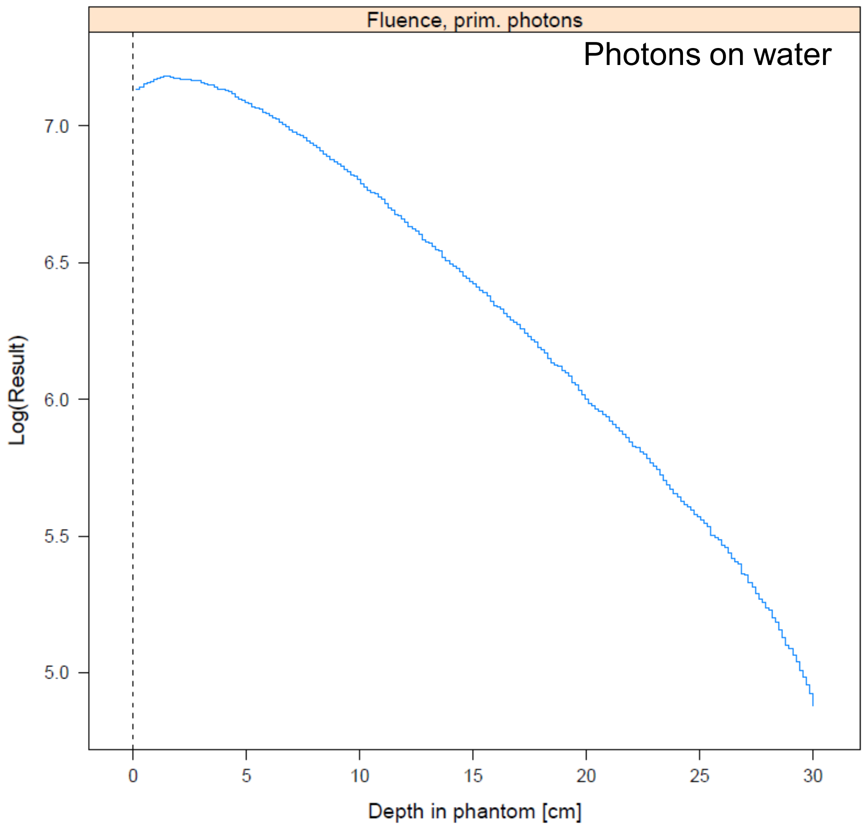
Compton

Filters for scorers

Example

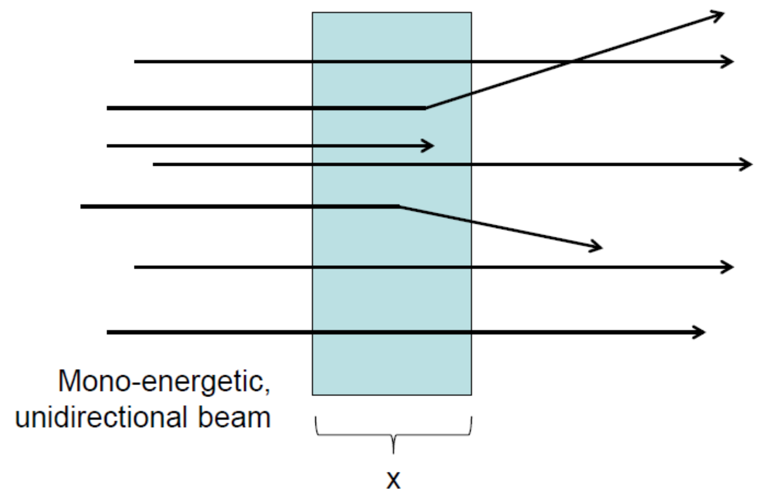
```
# Fluence of primary photons
s:Sc/FluenceScorer3/Quantity = "Fluence"
sv:Sc/FluenceScorer3/OnlyIncludeParticlesNamed = 1 "gamma"
s:Sc/FluenceScorer3/OnlyIncludeParticlesOfGeneration = "Primary"
```

Fluence of ”Topas primary photons” vs. depth in water for 500 keV photons



Exponential attenuation

Φ_0 $\quad \Phi(x) = \Phi_0 \exp(-\mu x)$



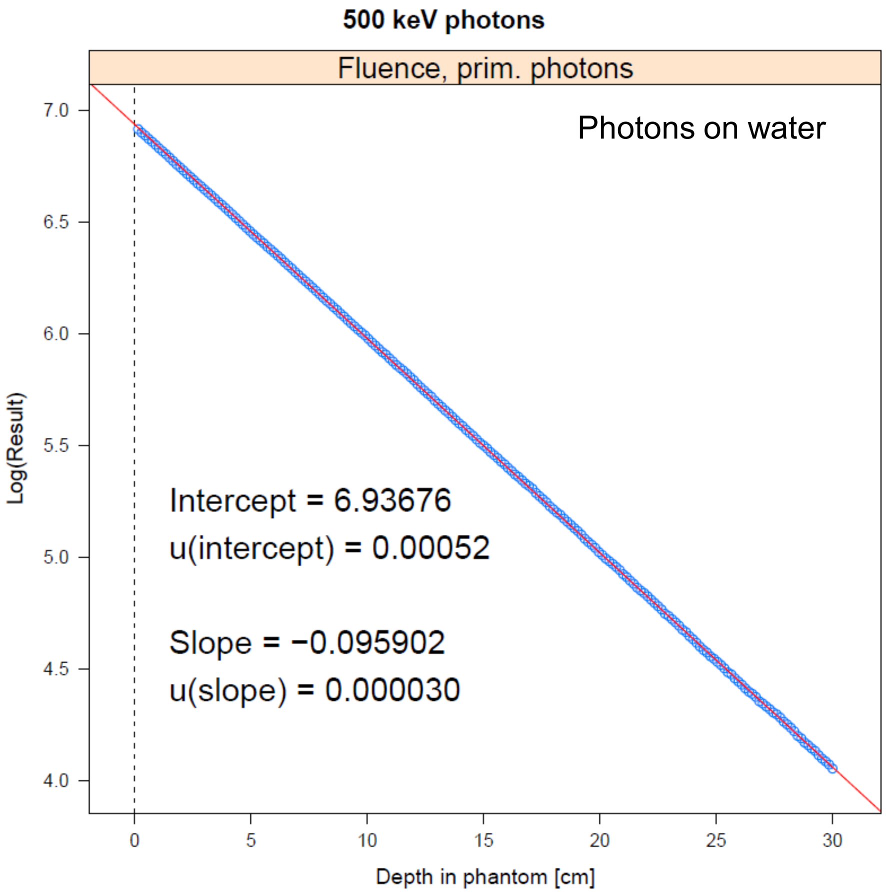
μ is the linear attenuation coefficient = the probability for interaction pr. unit distance pr. photon

Q: Why is the fluence of primary photons **not** governed by exponential attenuation??
A: Because ”primary photons” in Topas terminology is not what is primary in the normal sense that they have not undergone any form of interaction.
So, to get truely ”primary” photons it is not enough to request Topas to give primaries.

Filters for scorers

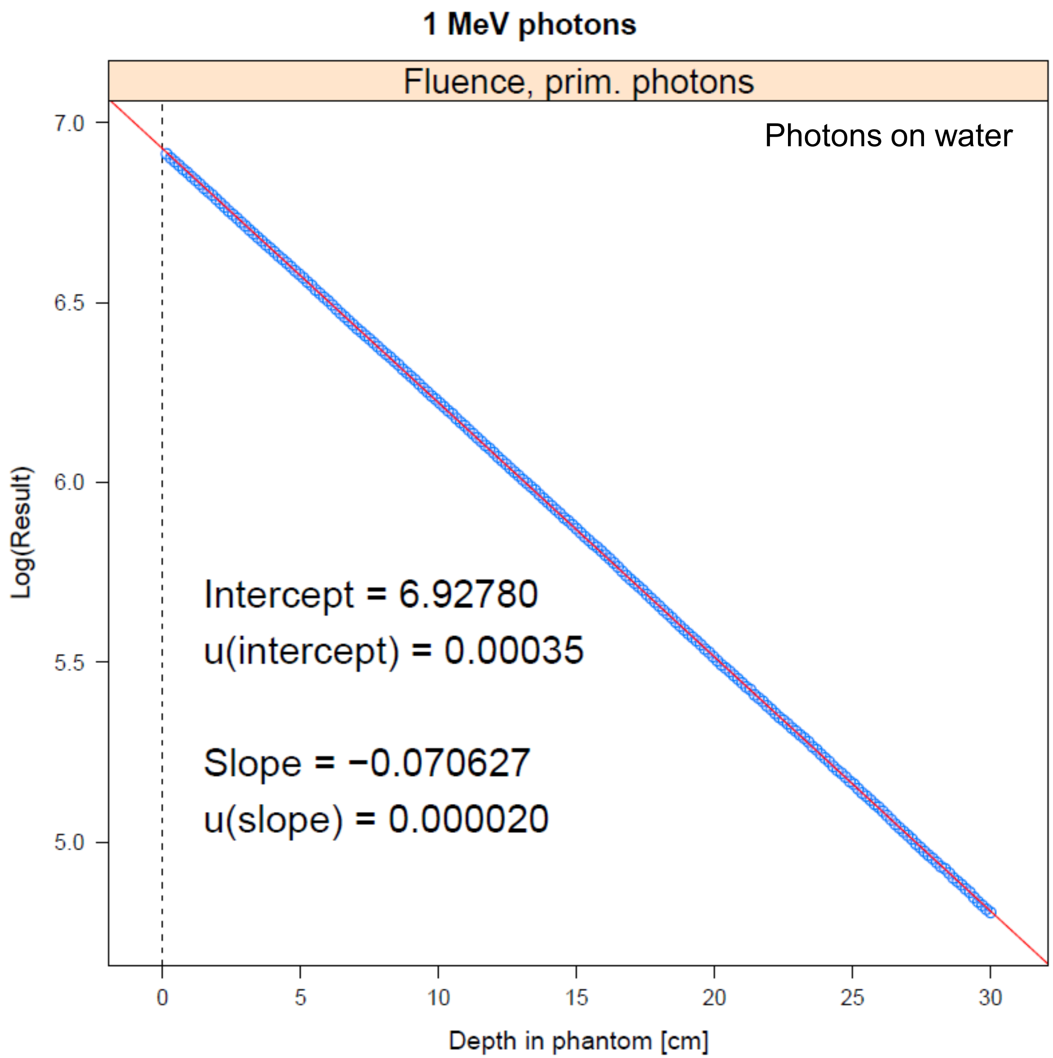
Example

```
# Fluence of primary photons
s:Sc/FluenceScorer3/Quantity = "Fluence"
sv:Sc/FluenceScorer3/OnlyIncludeParticlesNamed = 1 "gamma"
s:Sc/FluenceScorer3/OnlyIncludeParticlesOfGeneration = "Primary"
d:Sc/FluenceScorer3/OnlyIncludeIfIncidentParticleKEAbove = 0.495 MeV
```



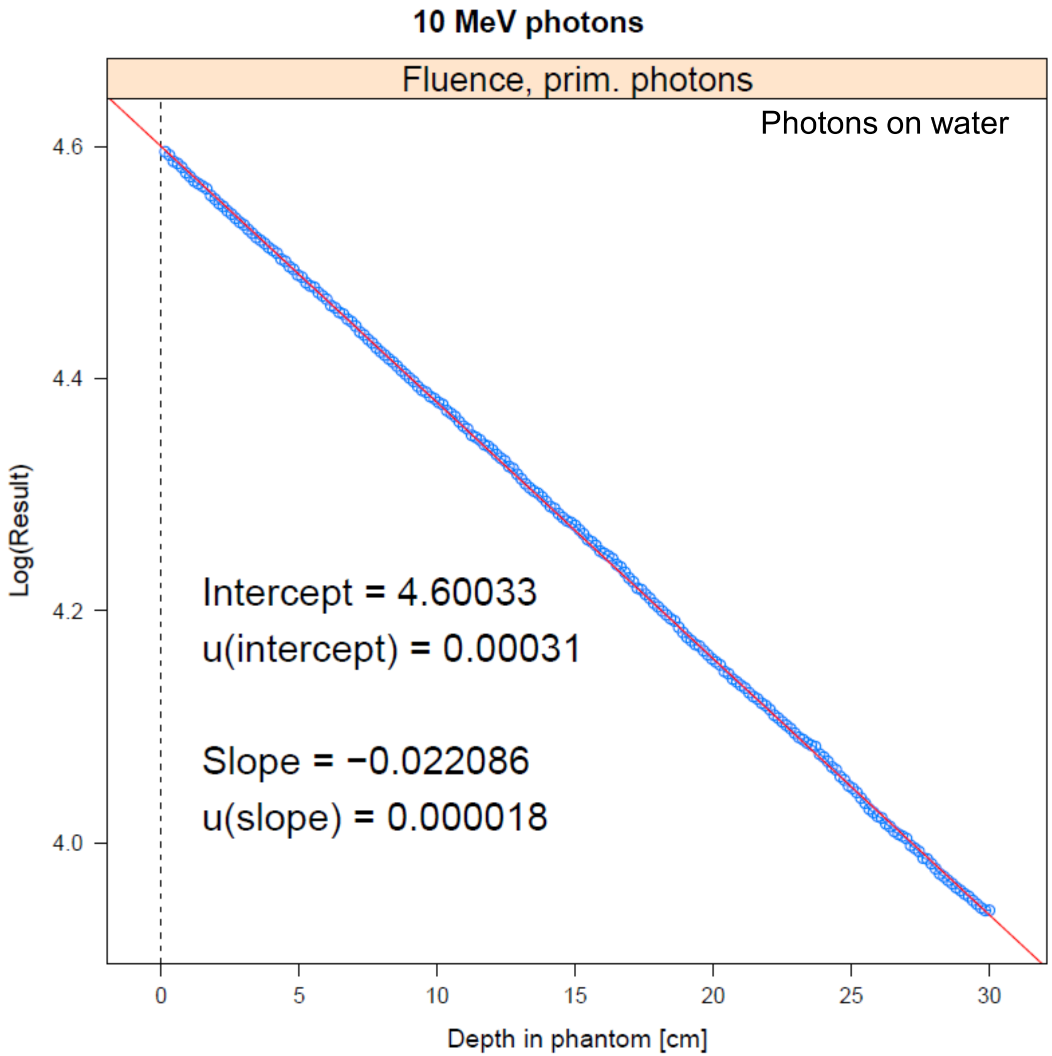
We also filter by energy to get the ”true” primaries only.

Now, we can confirm exponential attenuation. The mu for 500 keV photons is the negative slope of the semi-log regression: mu = 0.095902 1/cm which is in reasonable agreement with the 0.0966 1/cm given by Attix, Appendix D.



Good agreement with the 0.0706 1/cm given by Attix, Appendix D.

Filters for scorers
Example



Good agreement with the 0.0222 1/cm given by Attix, Appendix D.

In what direction does the particle source shoot?

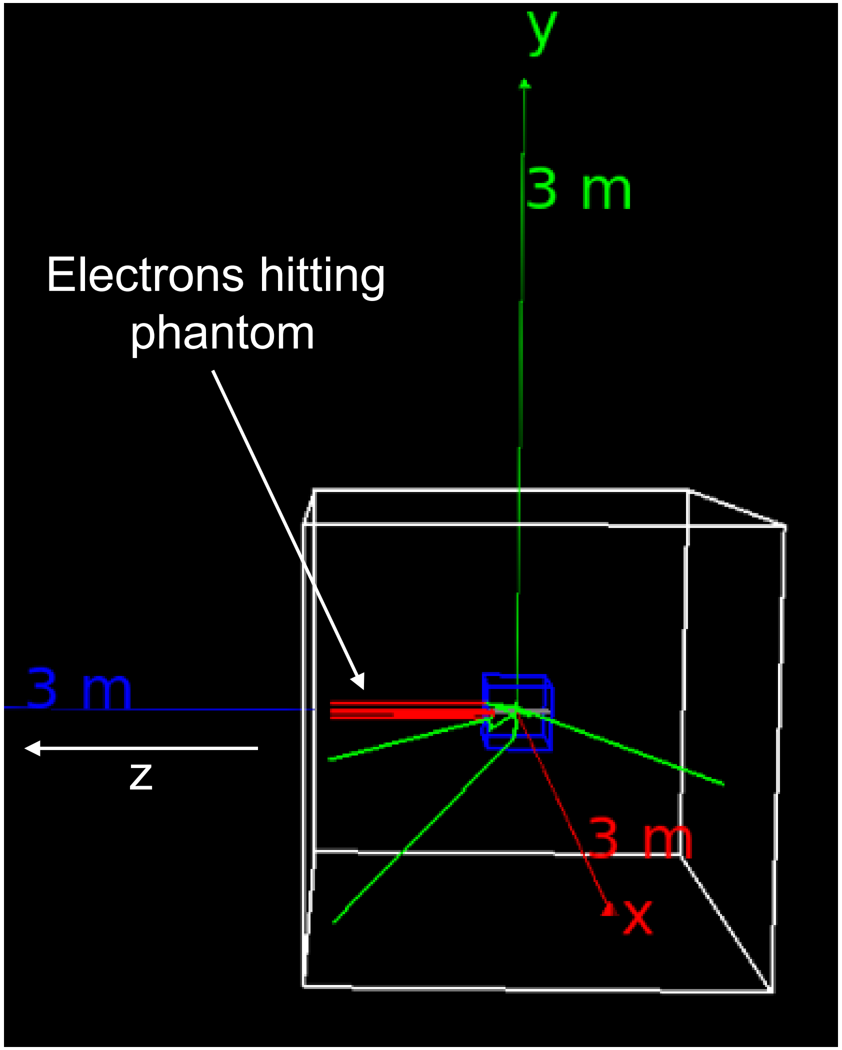
Meaning of TransZ and RotX for source components

```
# Beam position, With RotX = 180 deg,
the beam will be in the negative z-axis direction

s:Ge/clanBeamPosition/Parent = "World”
s:Ge/clanBeamPosition/Type = "Group”
d:Ge/clanBeamPosition/TransX = 0. m
d:Ge/clanBeamPosition/TransY = 0. m
d:Ge/clanBeamPosition/TransZ =  0.9 * Ge/World/HLZ m
d:Ge/clanBeamPosition/RotX = 180. deg
d:Ge/clanBeamPosition/RotY = 0. deg
d:Ge/clanBeamPosition/RotZ = 0. deg

# Beam
s:So/clanBeam/Type                = "Beam"
s:So/clanBeam/Component           = "clanBeamPosition”
s:So/clanBeam/BeamParticle        = "e-”
d:So/clanBeam/BeamEnergy          =  10 MeV
```

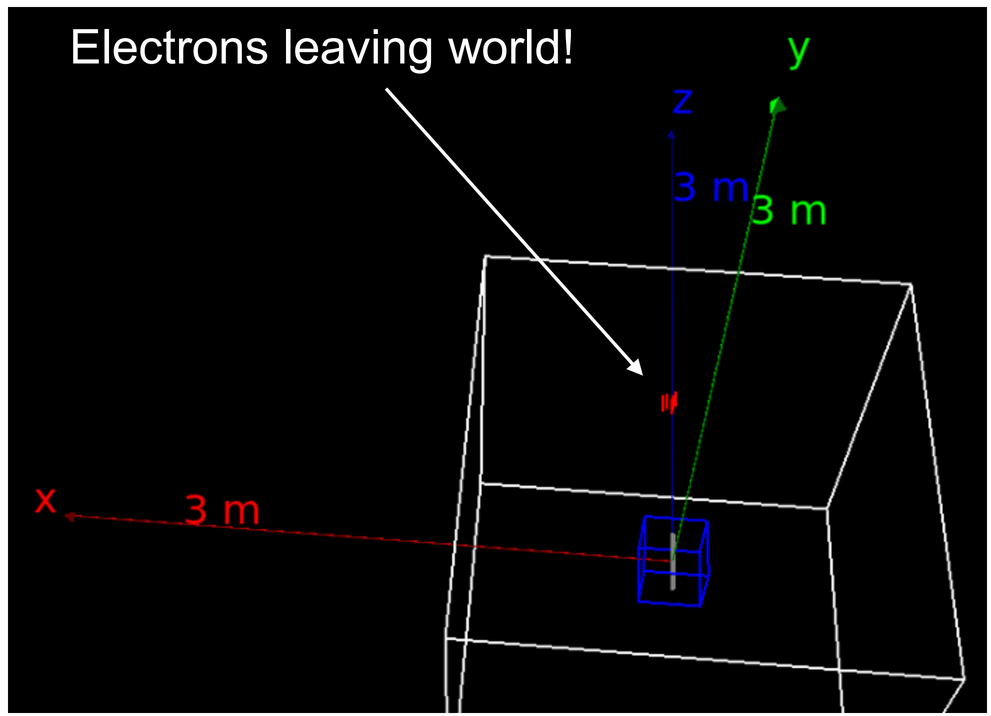
Note the unit

Rotate with x-axis
as normal vector

Case 1 (ok)
d:Ge/BeamPosition/RotX = 180. deg
Shooting in negative z-direction

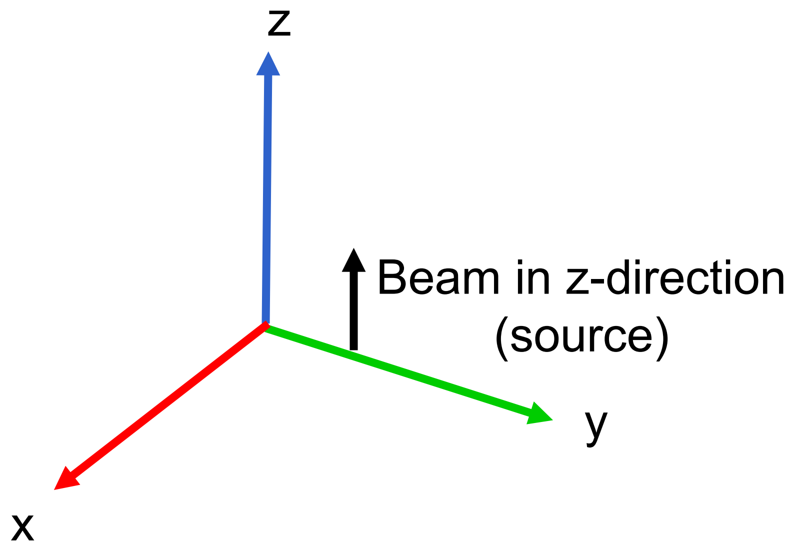


Case 2 (not ok)
d:Ge/BeamPosition/RotX = 0. deg
Shooting in positive z-direction.
Since the source is a bit from
the world edge, we see small
traces of the beam particles
before they leave.

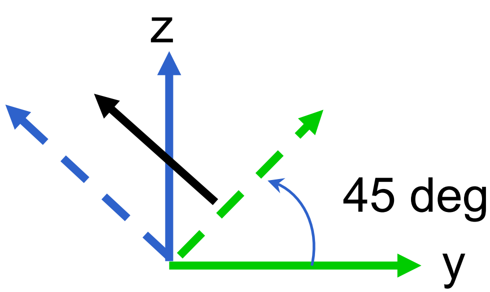


White box = world
Source is at z = 0.9 x HLZ for world

Meaning of RotX = 45.0 deg?



Rotate source 45 deg around the x-axis (i.e. the x-axis as normal vector and then rotate 45 deg following the right-hand-rule).



Side view
(from x-axis)

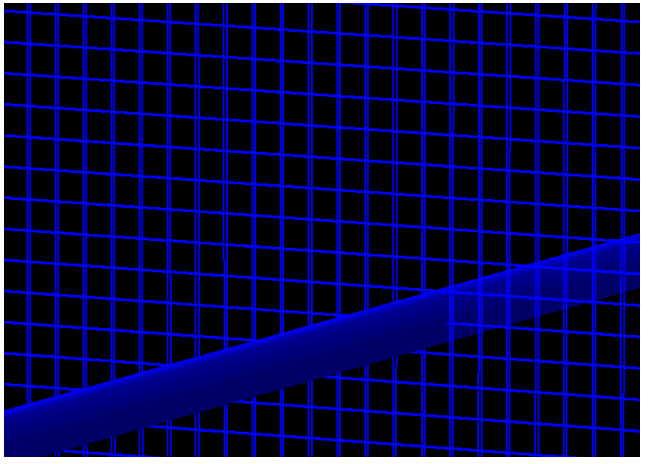
Rotated beam xrot = 45 deg (still perpendicular with x-axis).

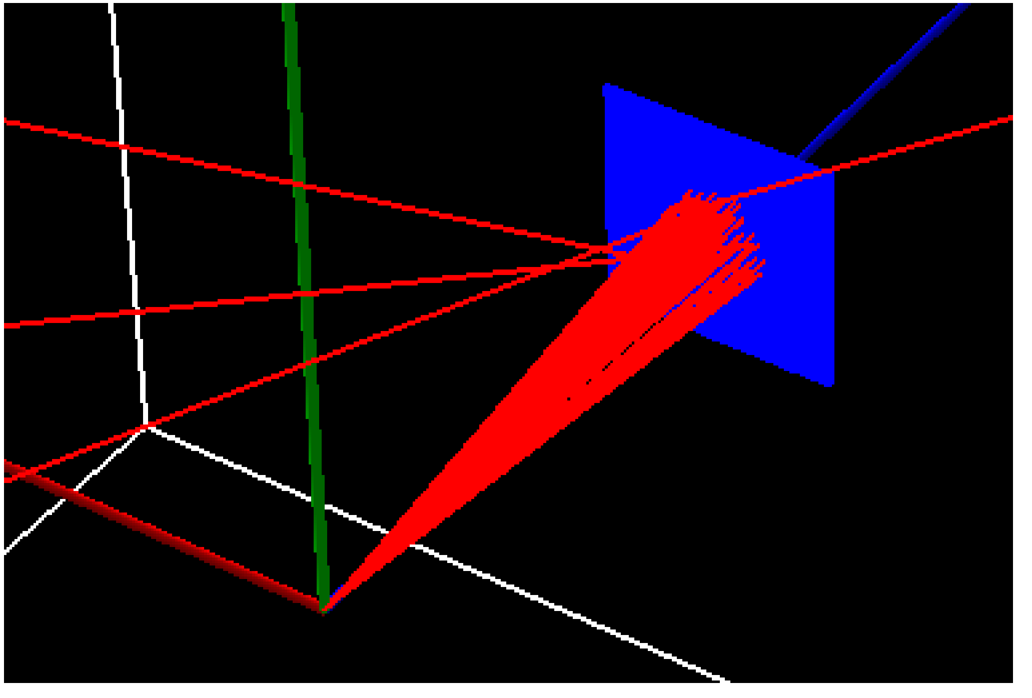
Rotating source RotX = 180 deg means that the source emits in the negative z-direction.

Beam shape parameters

Scoring beam intensity using a 40 cm x 40 cm ”flatpanel detector” 1 m from the source

```
# The flatpanel (40 x 40 resoltion)
s:Ge/flatpanel/Type      = "TsBox"
s:Ge/flatpanel/Material = "Water_75eV"
s:Ge/flatpanel/Parent    = "World"
d:Ge/flatpanel/HLX       = 20 cm
d:Ge/flatpanel/HLY       = 20 cm
d:Ge/flatpanel/HLZ       = 1 mm
d:Ge/flatpanel/TransX    = 0. m
d:Ge/flatpanel/TransY    = 0. m
d:Ge/flatpanel/TransZ    = 1. m
d:Ge/flatpanel/RotX      = 0. deg
d:Ge/flatpanel/RotY      = 0. deg
d:Ge/flatpanel/RotZ      = 0. deg
s:Ge/flatpanel/color     = "blue"
i:Ge/flatpanel/XBins = 40
i:Ge/flatpanel/YBins = 40
```





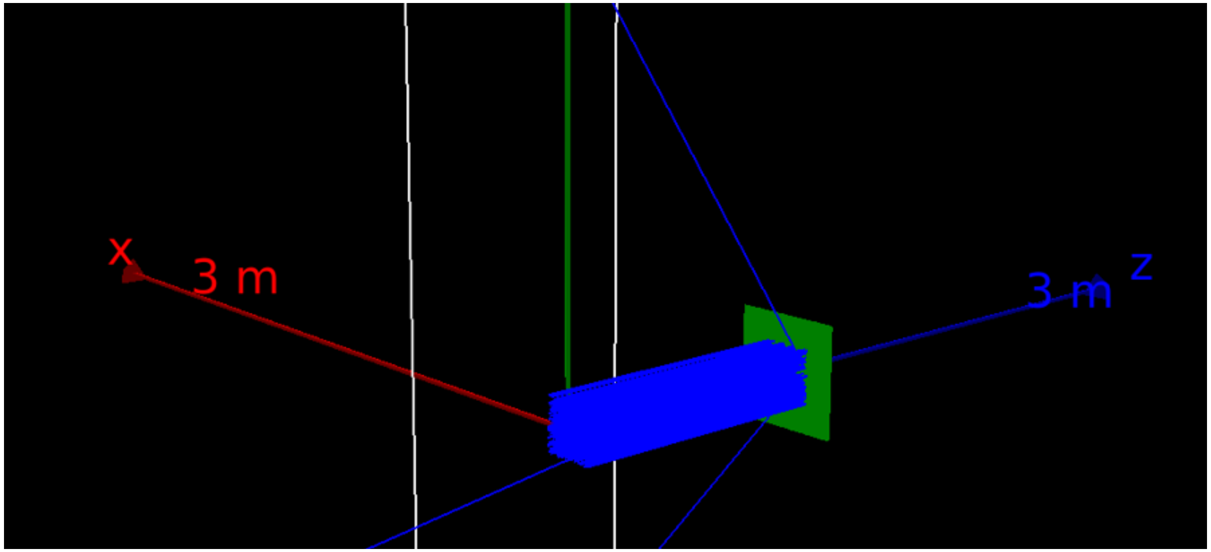
The ”flatpanel” scorer will give a 40 x 40 = 1600 (voxels) array of dose values.

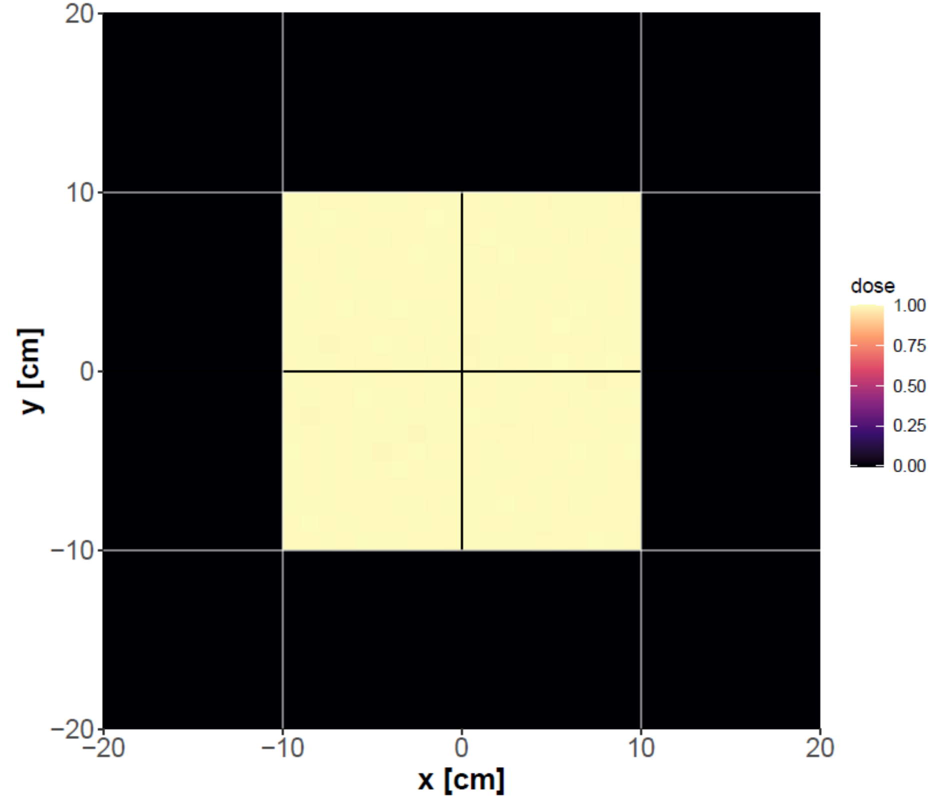
NOTE: This gives a parallel beam, 20 cm x 20 cm

Case 1

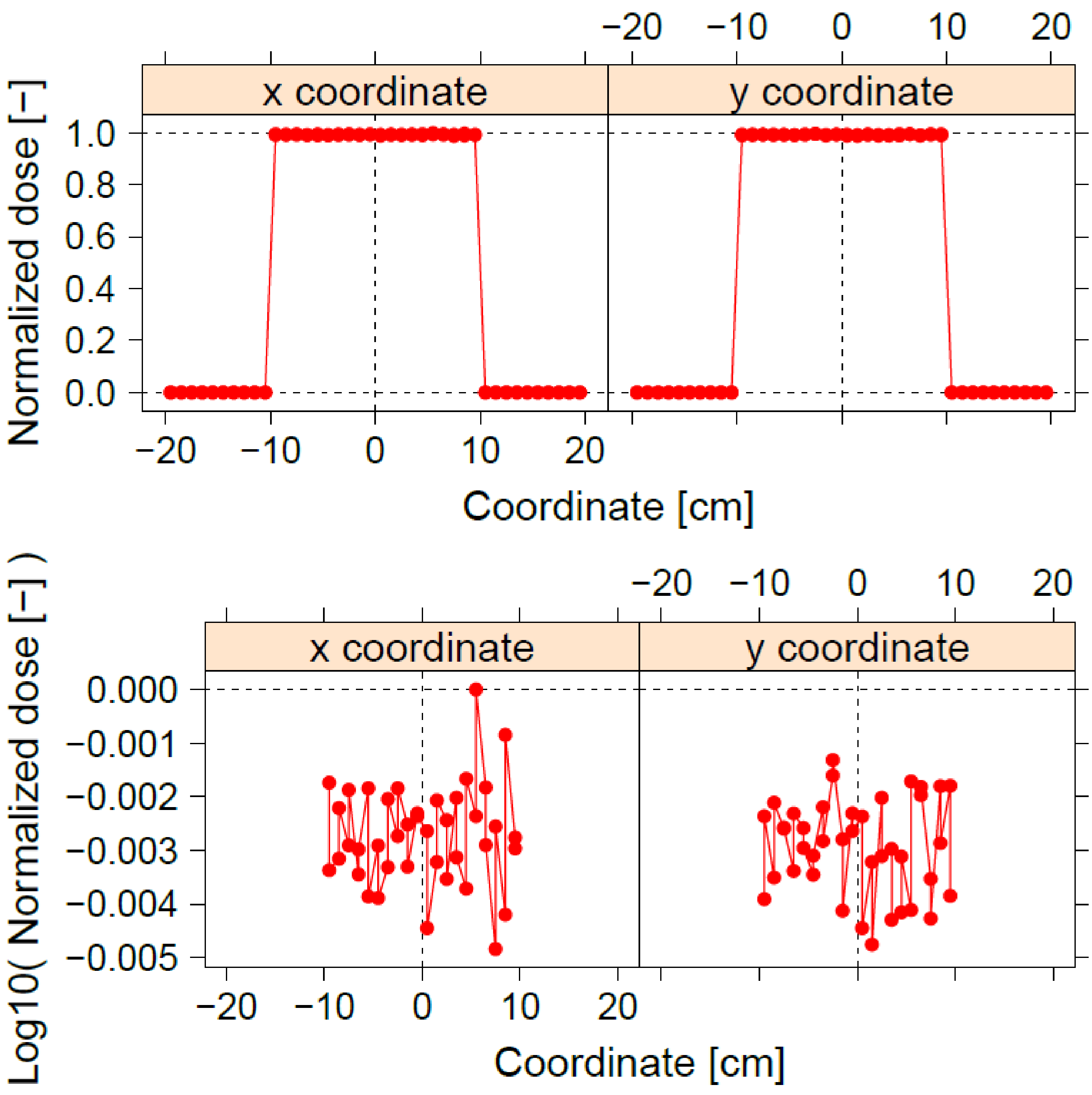
```
s:So/clanBeam/BeamPositionDistribution = "Flat"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = "Rectangle"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 100.0 mm
d:So/clanBeam/BeamPositionCutoffY = 100.0 mm

d:So/clanBeam/BeamPositionSpreadX = 0.0 mm
d:So/clanBeam/BeamPositionSpreadY = 0.0 mm

s:So/clanBeam/BeamAngularDistribution = "None"
d:So/clanBeam/BeamAngularCutoffX = 0.0 deg
d:So/clanBeam/BeamAngularCutoffY = 0.0 deg

d:So/clanBeam/BeamAngularSpreadX = 0.0 deg
d:So/clanBeam/BeamAngularSpreadY = 0.0 deg
```

Case 1





Case 1

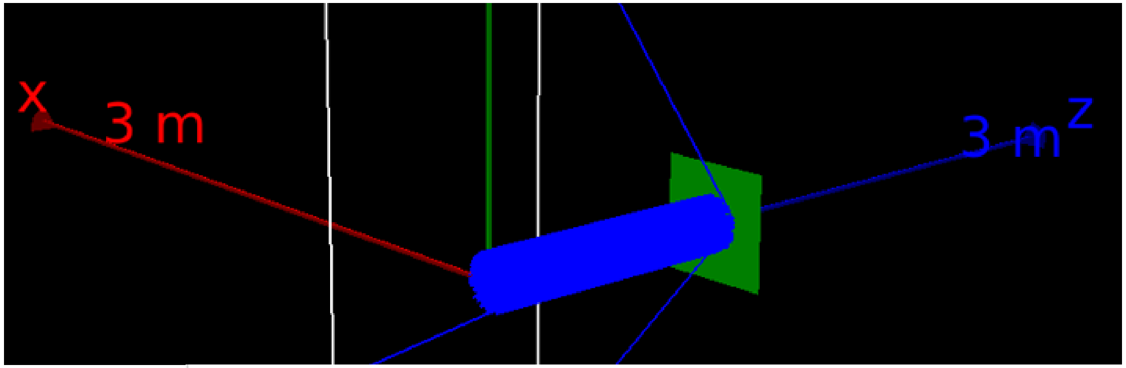

x coordinate
y coordinate
Normalized dose [–]
Coordinate [cm]
Log10(Normalized dose [–])
Coordinate [cm]

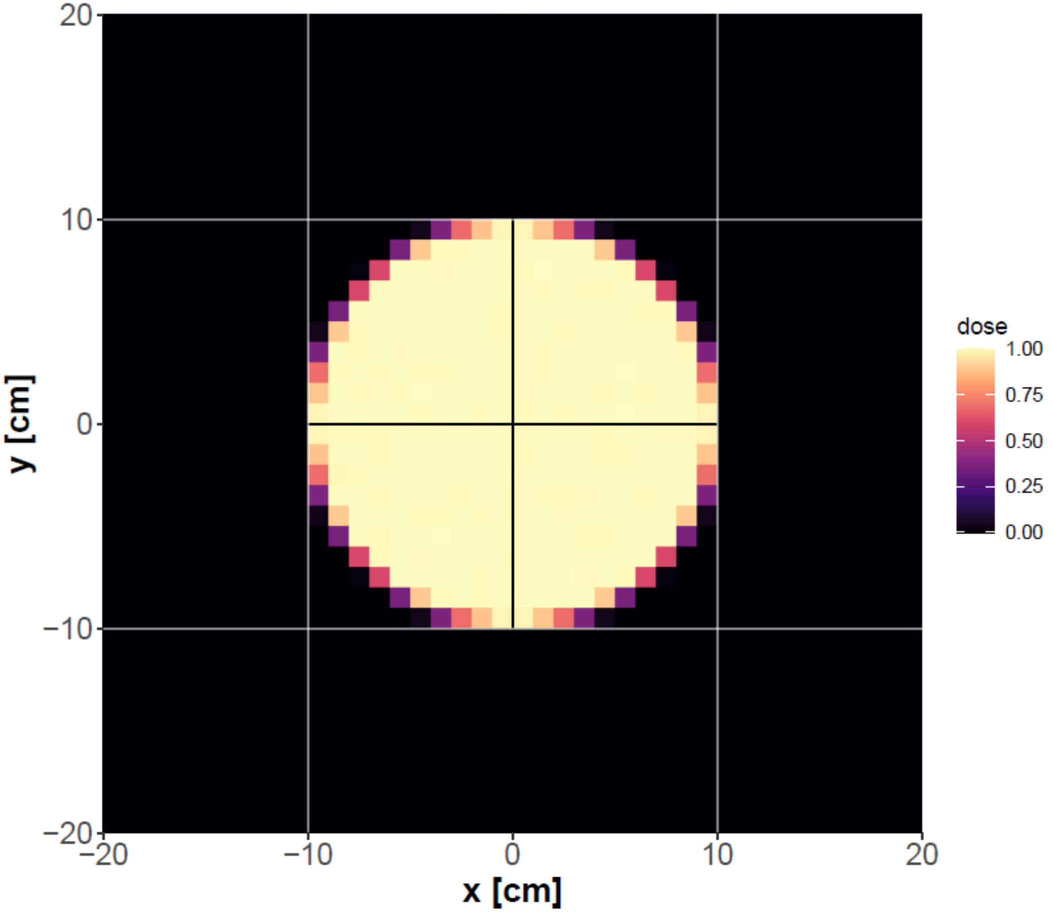
NOTE: This gives a parallel beam, circular beam w. 20 cm diameter

Case 2

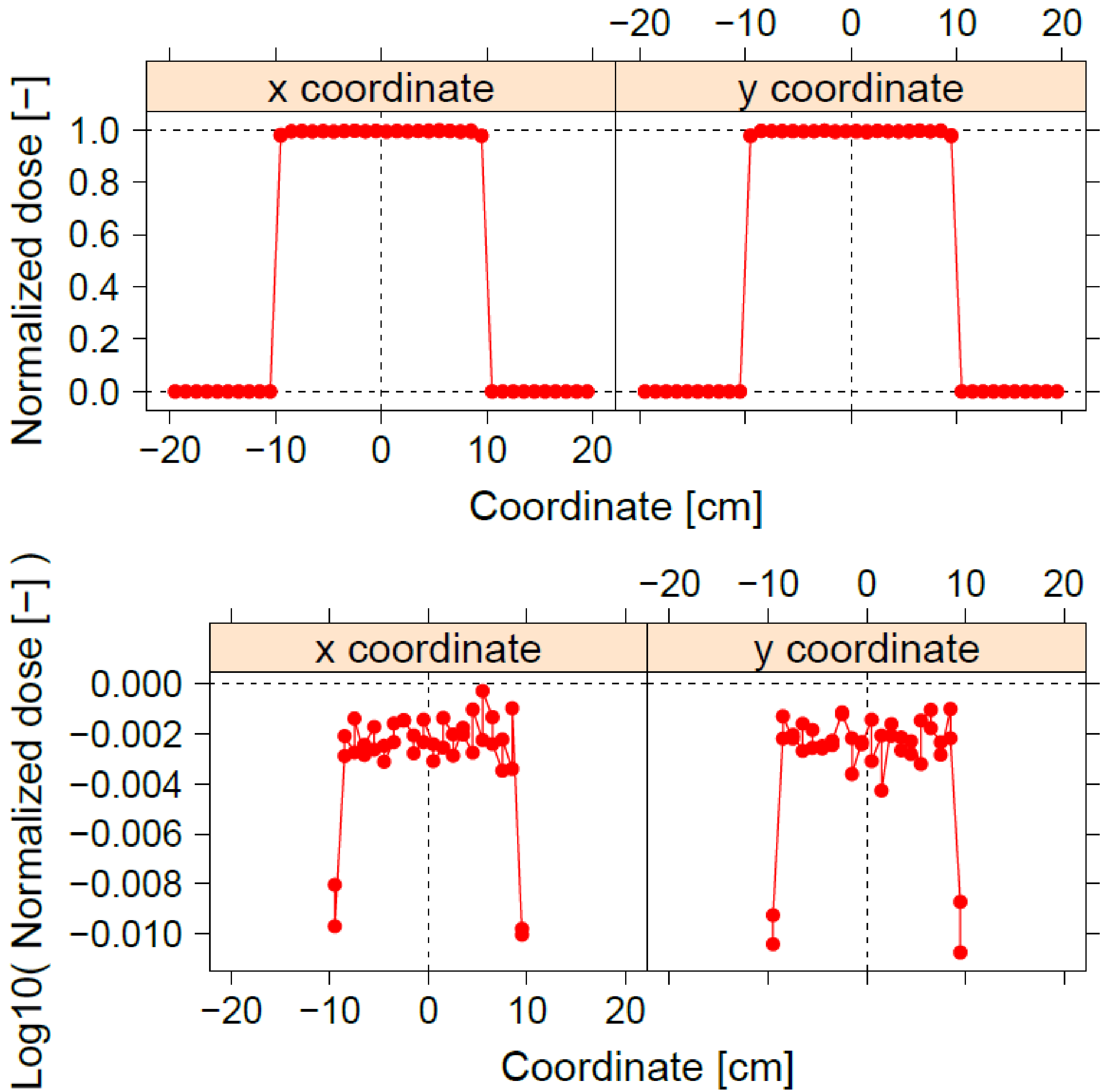
```
s:So/clanBeam/BeamPositionDistribution = "Flat"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = ”Ellipse"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 100.0 mm
d:So/clanBeam/BeamPositionCutoffY = 100.0 mm

d:So/clanBeam/BeamPositionSpreadX = 0.0 mm
d:So/clanBeam/BeamPositionSpreadY = 0.0 mm

s:So/clanBeam/BeamAngularDistribution = "None"
d:So/clanBeam/BeamAngularCutoffX = 0.0 deg
d:So/clanBeam/BeamAngularCutoffY = 0.0 deg

d:So/clanBeam/BeamAngularSpreadX = 0.0 deg
d:So/clanBeam/BeamAngularSpreadY = 0.0 deg
```

Case 2





Case 2



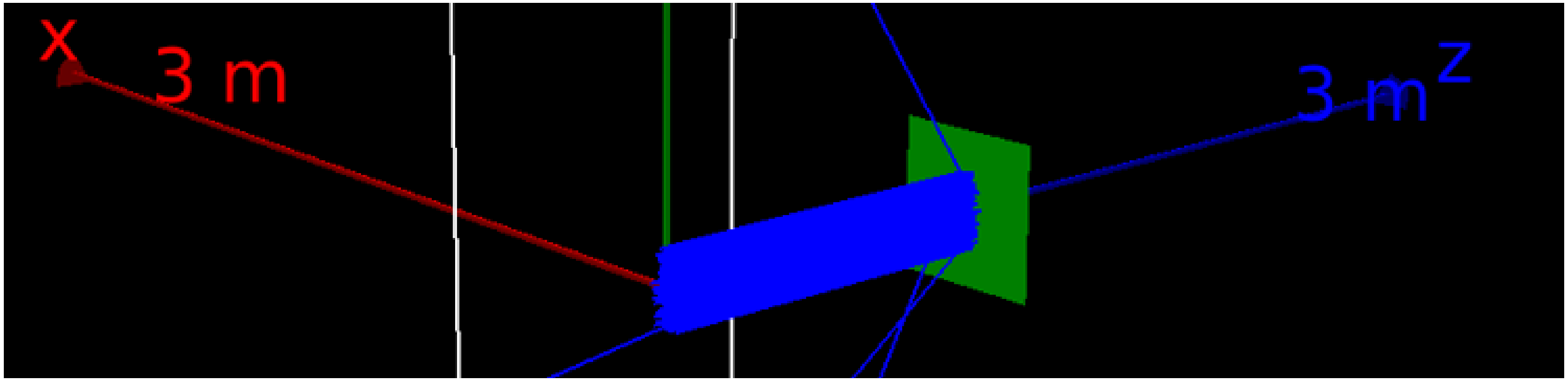
x coordinate
y coordinate
Normalized dose [−]
1.0
0.8
0.6
0.4
0.2
0.0
−20
−10
0
10
20
Coordinate [cm]
x coordinate
y coordinate
Log10(Normalized dose [−])
0.000
−0.002
−0.004
−0.006
−0.008
−0.010
−20
−10
0
10
20
Coordinate [cm]

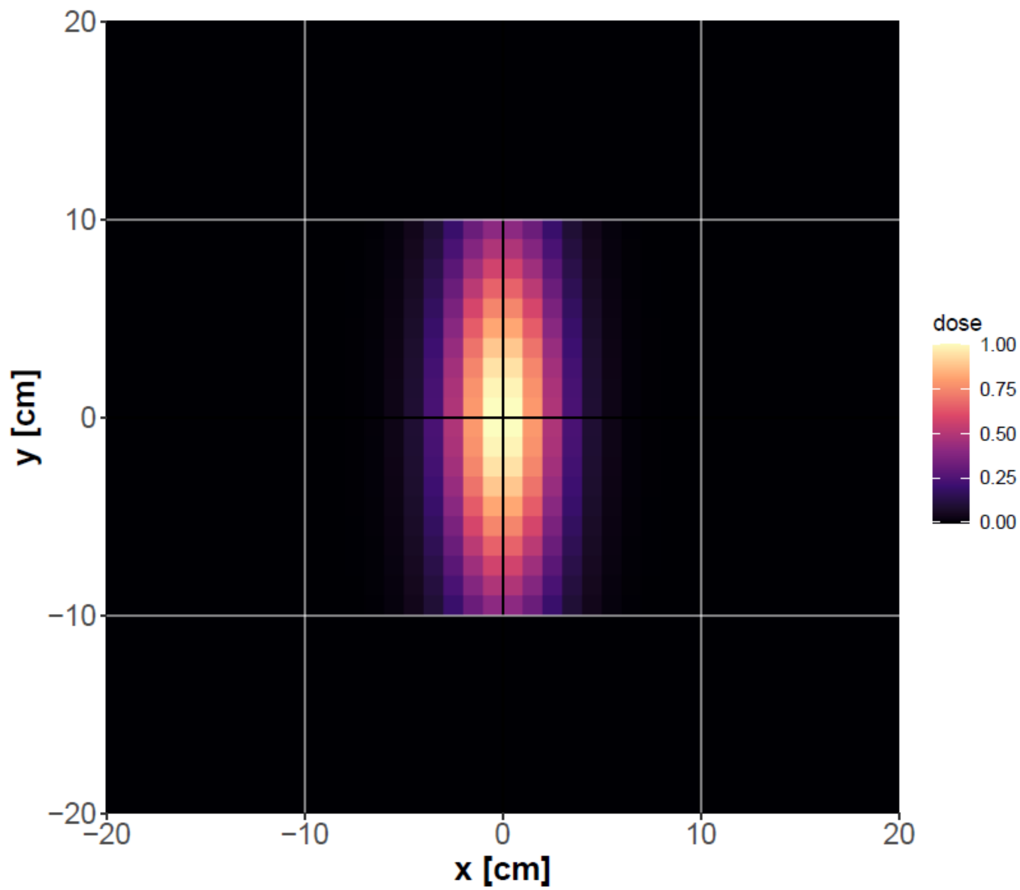
NOTE: Beam intensity described by gaussian parameters

Case 3

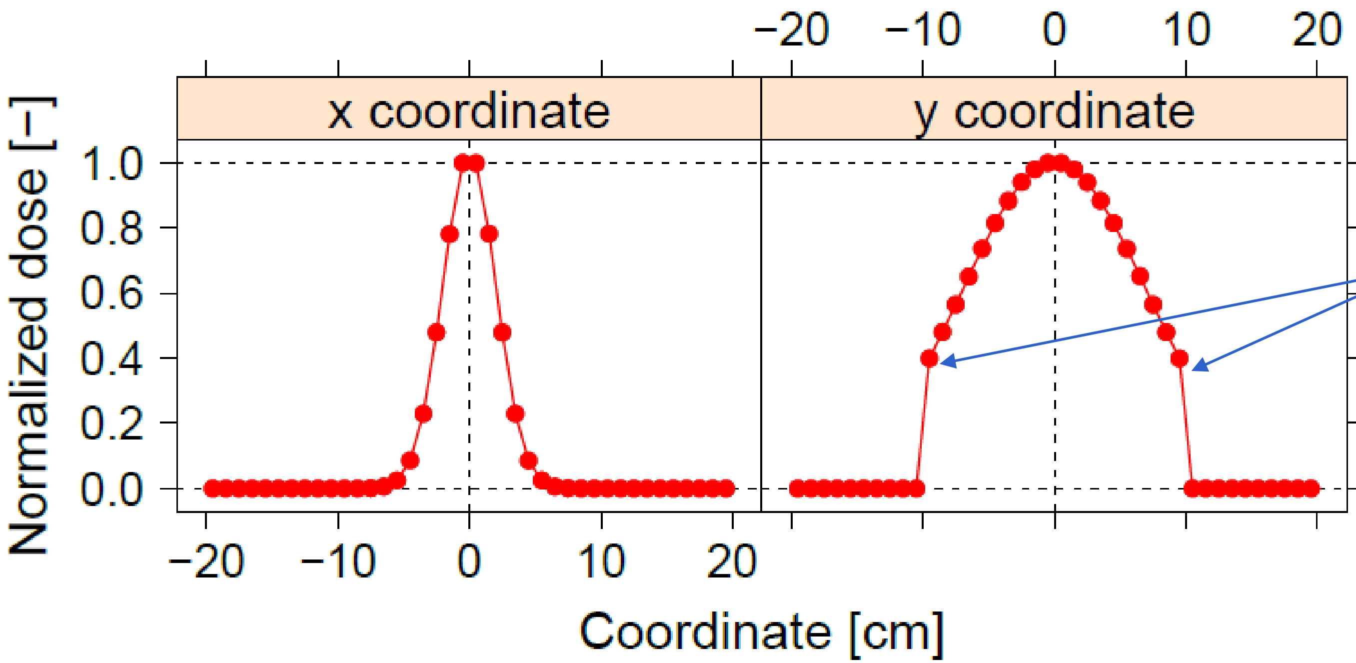
```
s:So/clanBeam/BeamPositionDistribution = ”Gaussian"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = ”Rectangle"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 100.0 mm
d:So/clanBeam/BeamPositionCutoffY = 100.0 mm

d:So/clanBeam/BeamPositionSpreadX = 20.0 mm
d:So/clanBeam/BeamPositionSpreadY = 70.0 mm

s:So/clanBeam/BeamAngularDistribution = "None"
d:So/clanBeam/BeamAngularCutoffX = 0.0 deg
d:So/clanBeam/BeamAngularCutoffY = 0.0 deg

d:So/clanBeam/BeamAngularSpreadX = 0.0 deg
d:So/clanBeam/BeamAngularSpreadY = 0.0 deg
```

Case 3

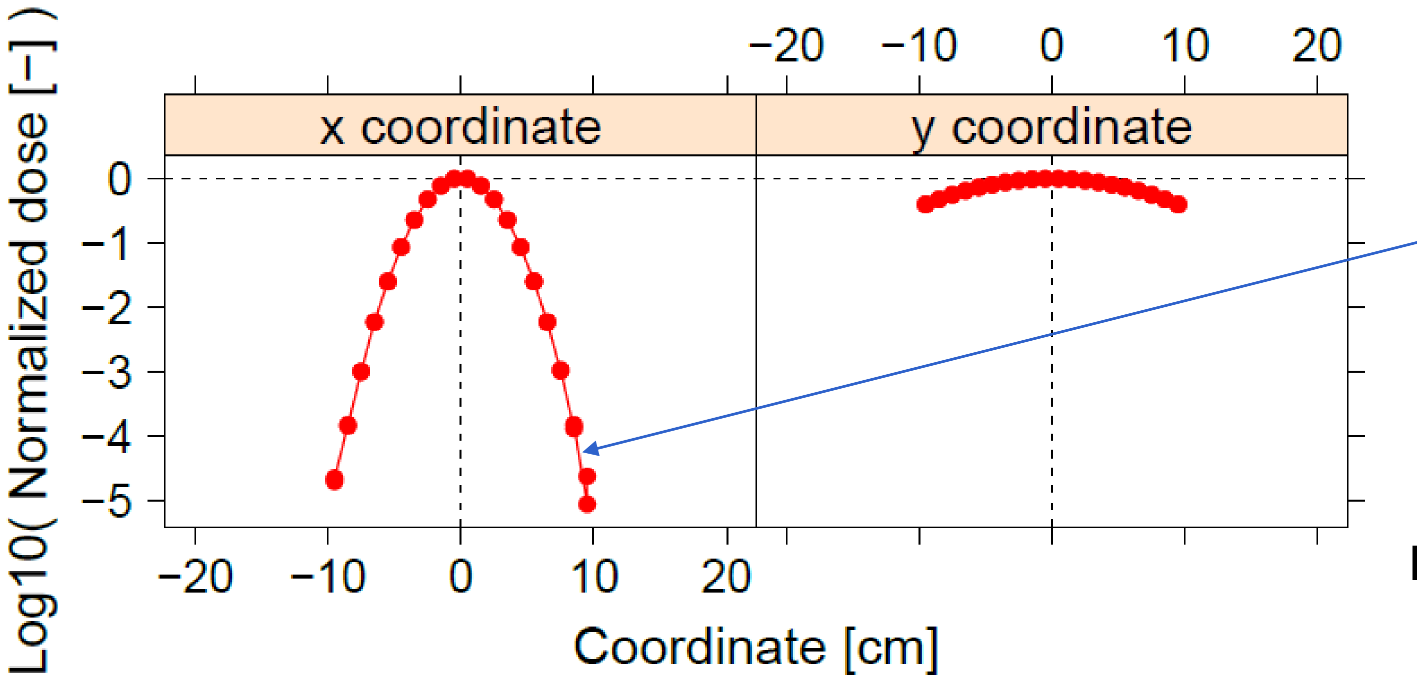




Case 3



Note the cuts at +/-10 cm (truncated gaussian)



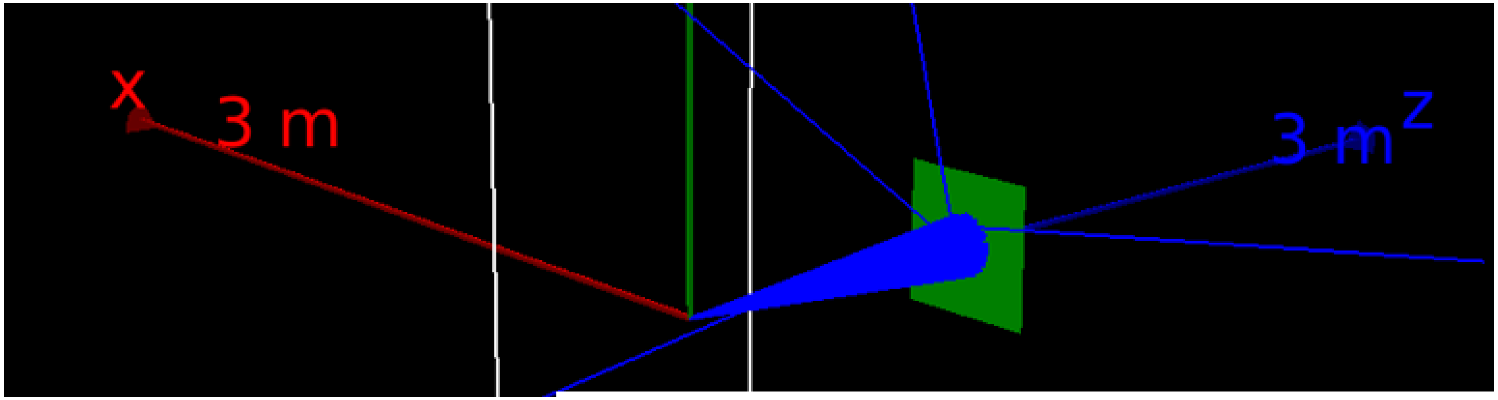
Note that the beam continues to +/- 10 cm cuts (but with very low intensity)

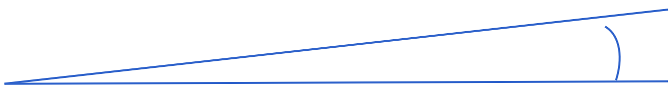
NOTE: Diverting point source

Case 4

```
s:So/clanBeam/BeamPositionDistribution = ”Flat"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = ”Rectangle"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 0.000001 mm
d:So/clanBeam/BeamPositionCutoffY = 0.000001 mm

d:So/clanBeam/BeamPositionSpreadX = 0.0 mm
d:So/clanBeam/BeamPositionSpreadY = 0.0 mm

s:So/clanBeam/BeamAngularDistribution = ”Flat"
d:So/clanBeam/BeamAngularCutoffX = 5.0 deg
d:So/clanBeam/BeamAngularCutoffY = 5.0 deg

d:So/clanBeam/BeamAngularSpreadX = 0.0 deg
d:So/clanBeam/BeamAngularSpreadY = 0.0 deg
```

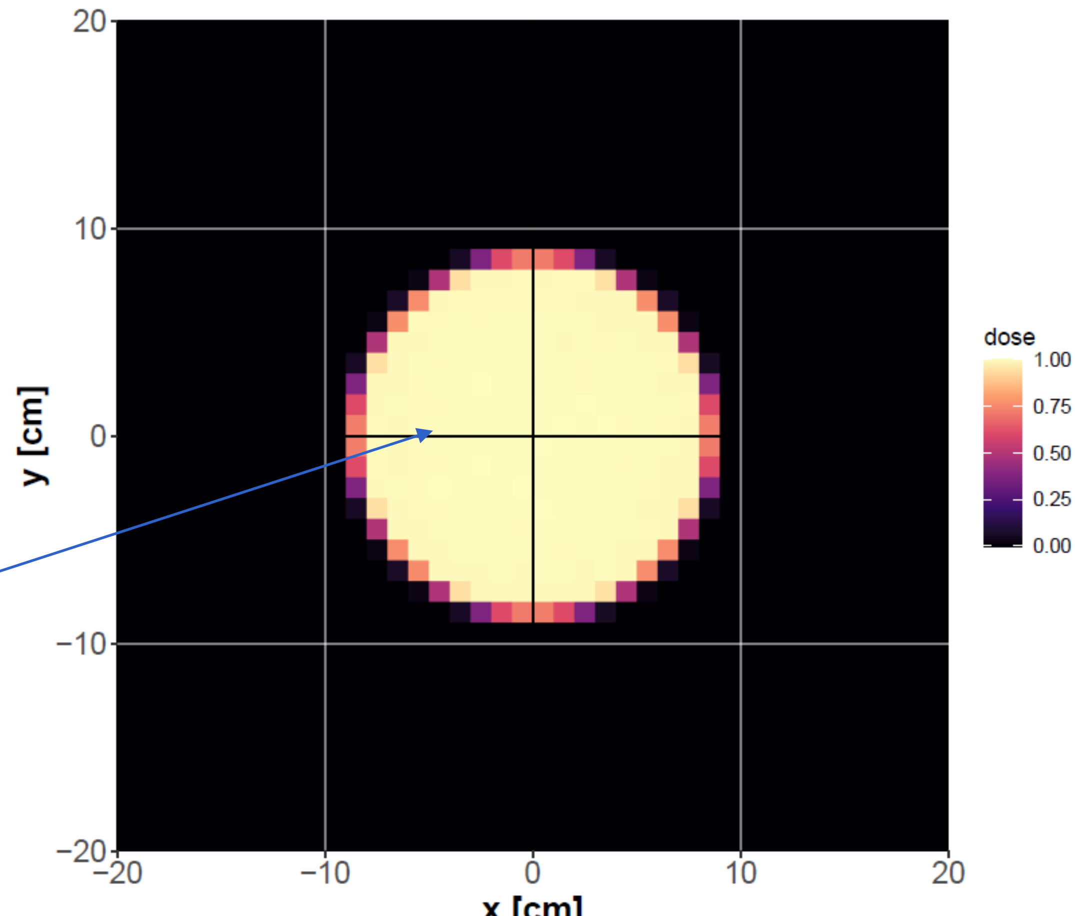
Case 4





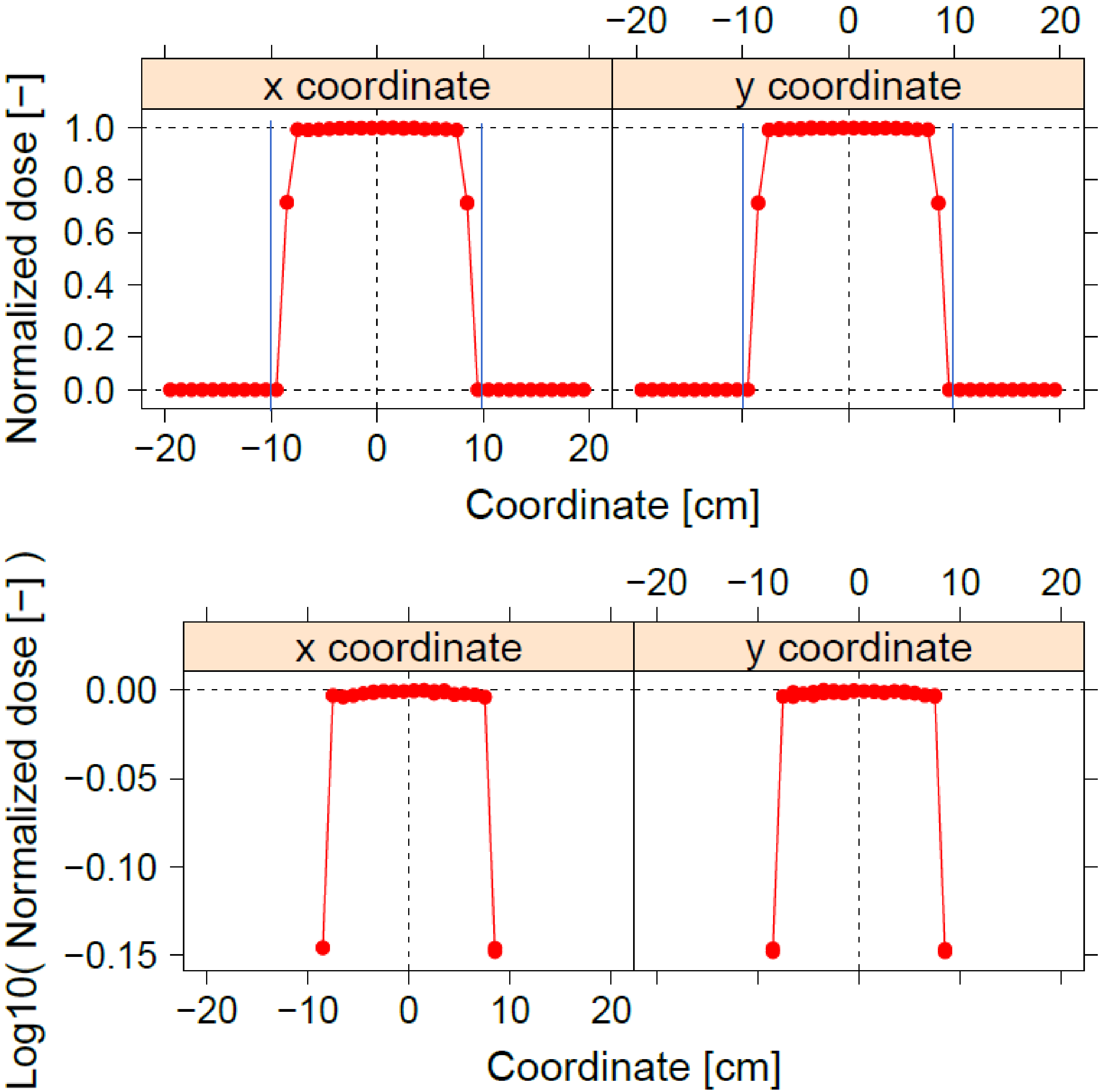
5 deg

Radius at flatpanel =
1 m x tan(5 deg) = 8.75 cm



NOTE:
The beam shape is not a rectangle !!! (important for simple MV linac simulations)

Case 4



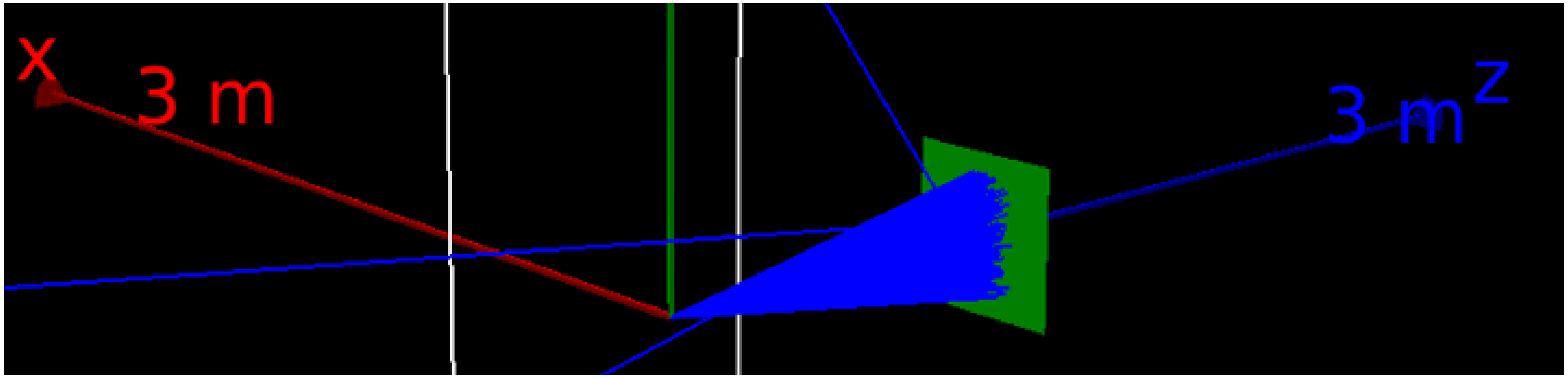
x coordinate
y coordinate
Normalized dose [–]
1.0
0.8
0.6
0.4
0.2
0.0
−20
−10
0
10
20
Coordinate [cm]
x coordinate
y coordinate
Log10(Normalized dose [–])
0.00
−0.05
−0.10
−0.15
−20
−10
0
10
20
Coordinate [cm]

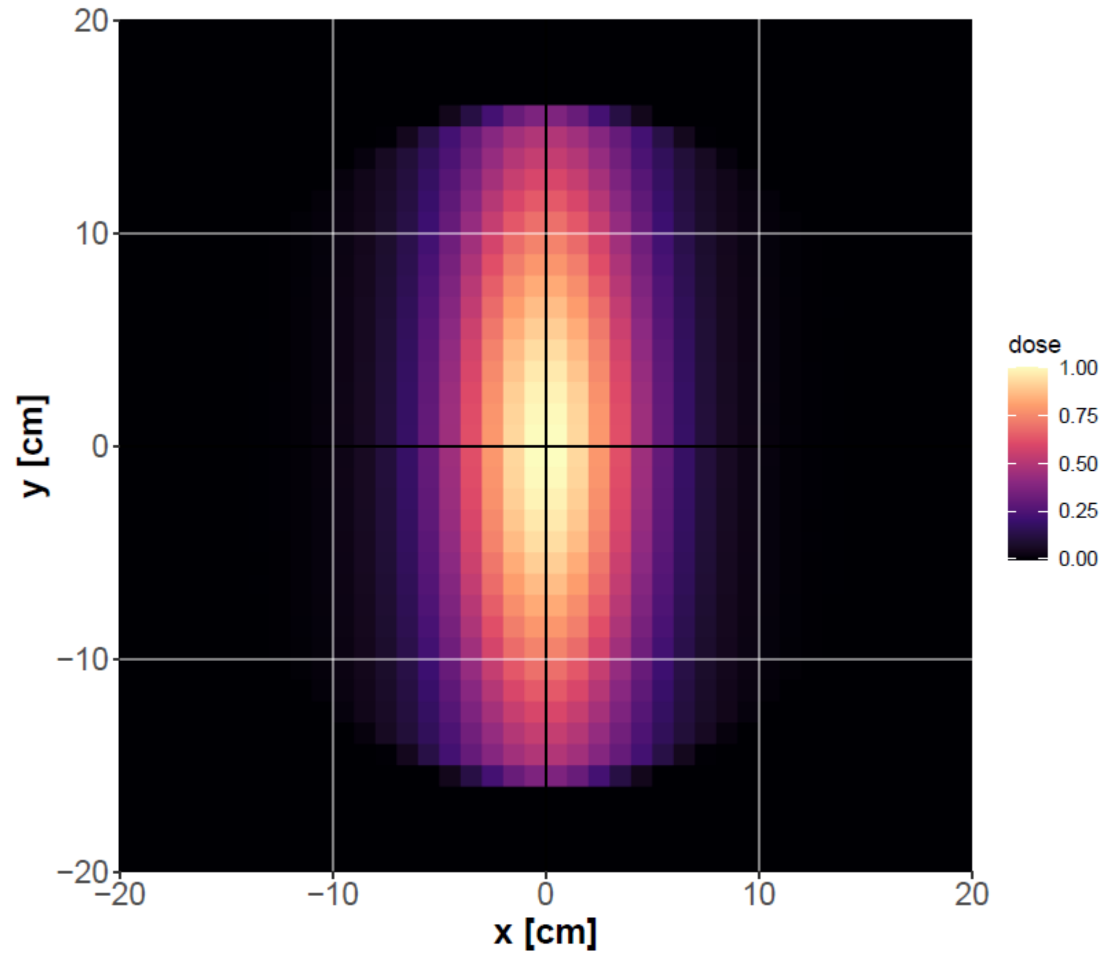
Case 5

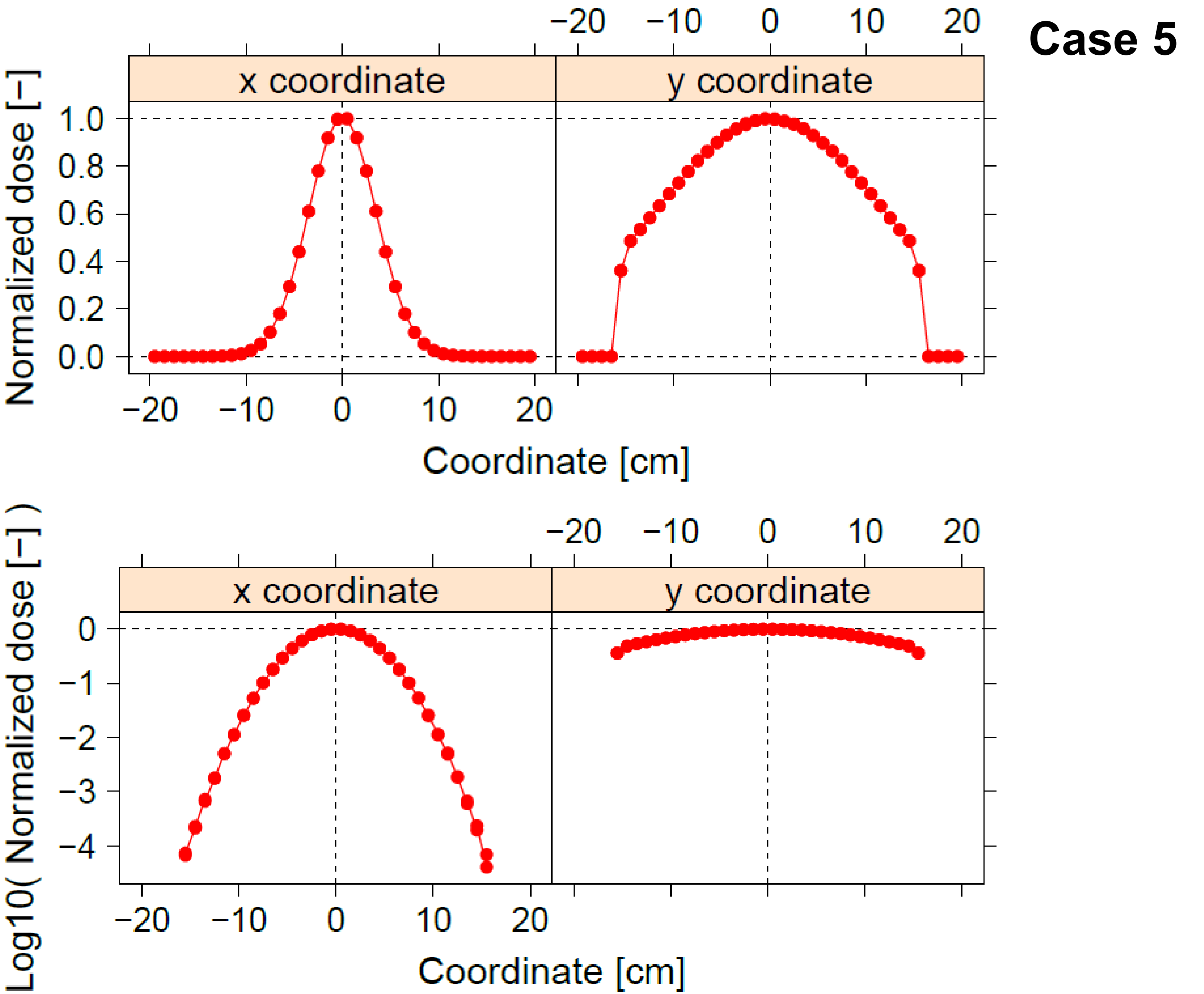
NOTE: Diverting point source

```
s:So/clanBeam/BeamPositionDistribution = ”Flat"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = ”Rectangle"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 0.000001 mm
d:So/clanBeam/BeamPositionCutoffY = 0.000001 mm

d:So/clanBeam/BeamPositionSpreadX = 0.0 mm
d:So/clanBeam/BeamPositionSpreadY = 0.0 mm

s:So/clanBeam/BeamAngularDistribution = ”Gaussian"
d:So/clanBeam/BeamAngularCutoffX = 9.0 deg
d:So/clanBeam/BeamAngularCutoffY = 9.0 deg

d:So/clanBeam/BeamAngularSpreadX = 2.0 deg
d:So/clanBeam/BeamAngularSpreadY = 7.0 deg
```

Case 5







Case 5
x coordinate
y coordinate
Normalized dose [−]
1.0
0.8
0.6
0.4
0.2
0.0
−20
−10
0
10
20
Coordinate [cm]
Log10(Normalized dose [−])
0
−1
−2
−3
−4

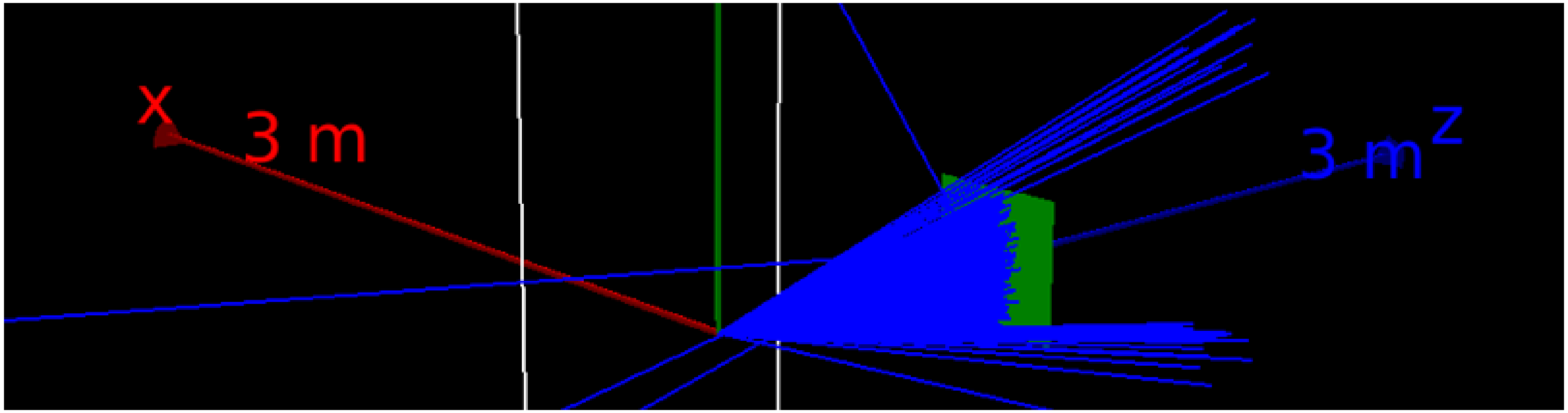
Case 6

NOTE: Diverting point source

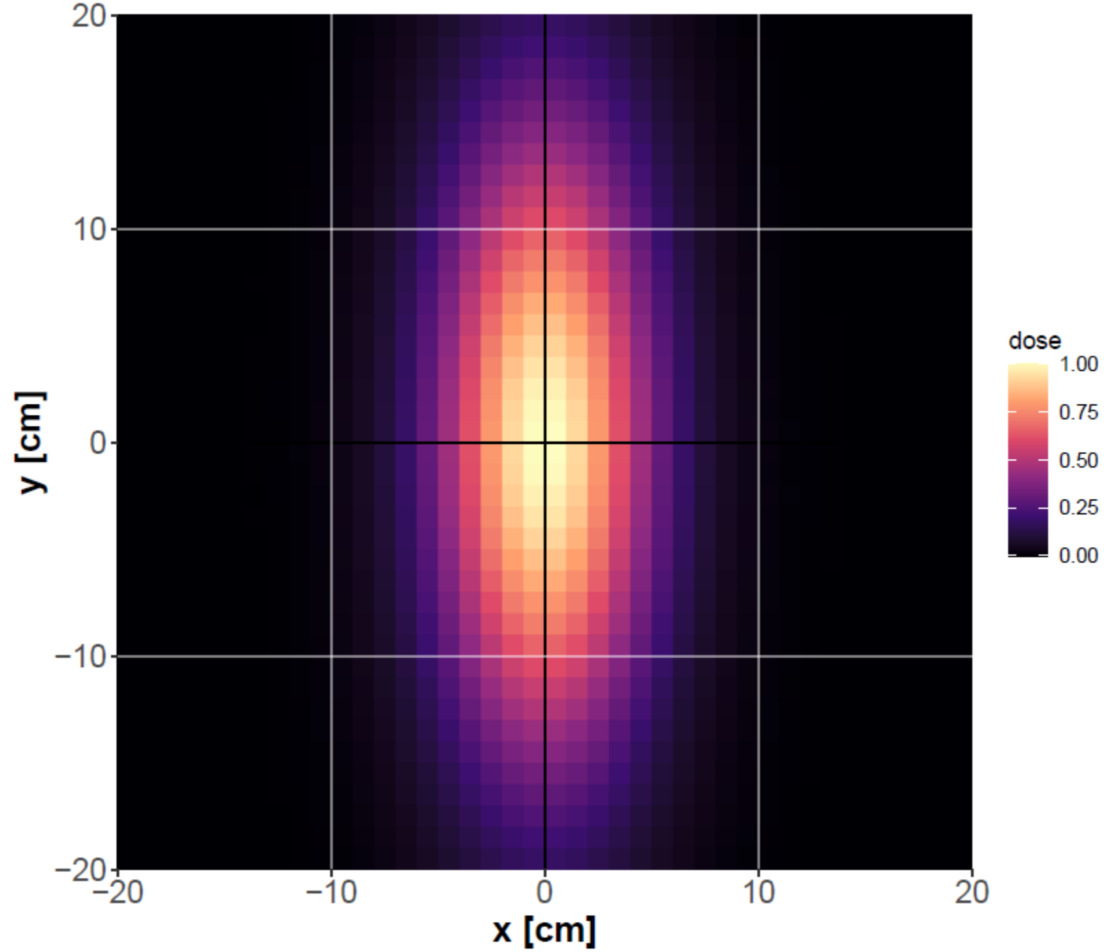
```
s:So/clanBeam/BeamPositionDistribution = ”Flat"
# Flat or Gaussian

s:So/clanBeam/BeamPositionCutoffShape  = ”Rectangle"
# Ellipse, Rectangle

d:So/clanBeam/BeamPositionCutoffX = 0.000001 mm
d:So/clanBeam/BeamPositionCutoffY = 0.000001 mm

d:So/clanBeam/BeamPositionSpreadX = 0.0 mm
d:So/clanBeam/BeamPositionSpreadY = 0.0 mm

s:So/clanBeam/BeamAngularDistribution = ”Gaussian"
d:So/clanBeam/BeamAngularCutoffX = 100.0 deg
d:So/clanBeam/BeamAngularCutoffY = 100.0 deg

d:So/clanBeam/BeamAngularSpreadX = 2.0 deg
d:So/clanBeam/BeamAngularSpreadY = 6.0 deg
```

Now, essentially no truncation of beam.

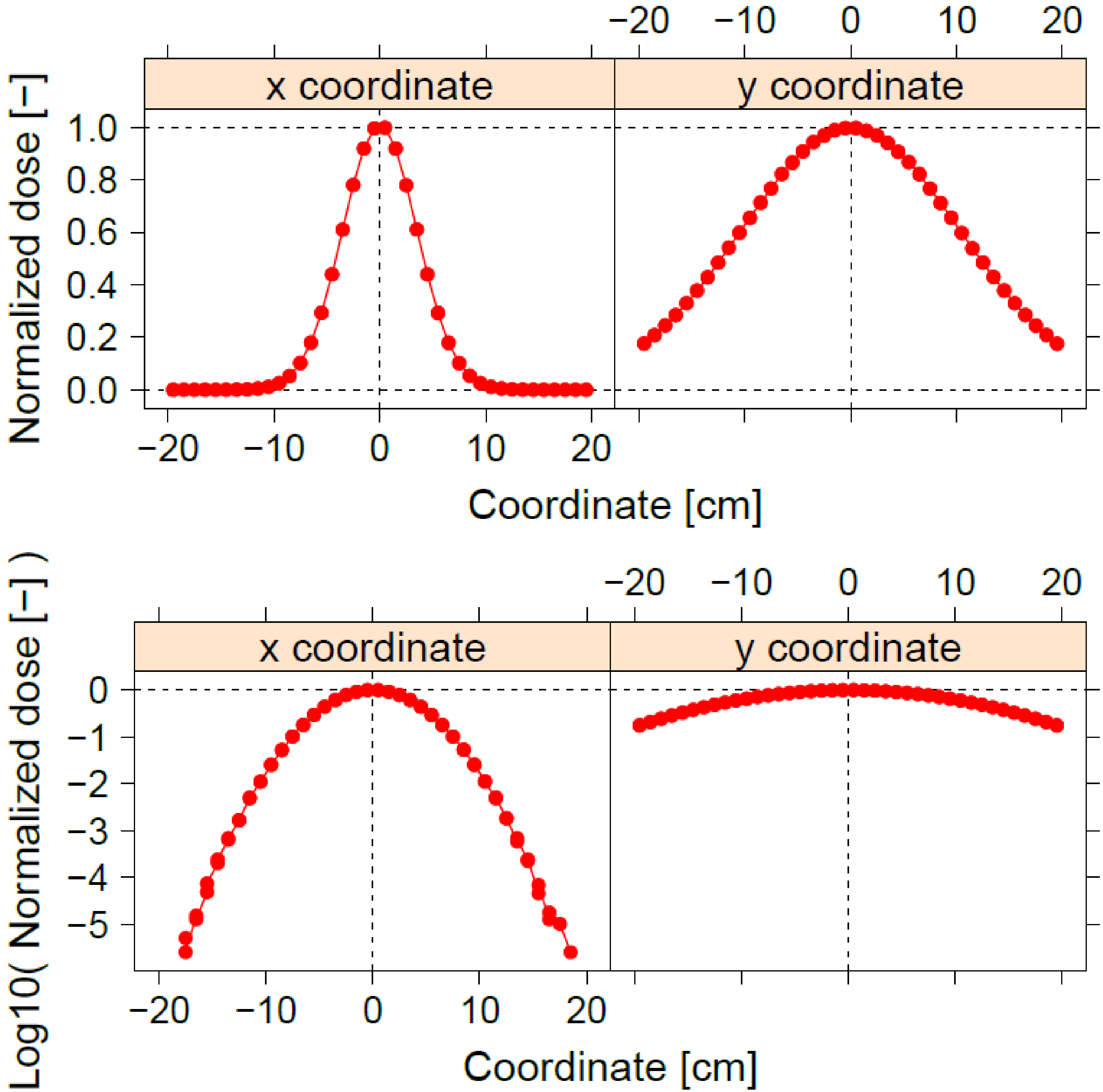
Case 6



Beam extends outside the flatpanel detector



Case 6


x coordinate
y coordinate
Normalized dose [–]
1.0
0.8
0.6
0.4
0.2
0.0
−20
−10
0
10
20
Coordinate [cm]
Log10(Normalized dose [–])
0
−1
−2
−3
−4
−5

Welcome to ”parallel worlds” !

You can now score with different resolutions and across components.

Wunderful !!!

How to score multiple quantities in a component using different resolutions?

Answer: Use a parallel-world component without mass or material:

```
# Flatpanel2 (10 x 10 resolution)
b:Ge/flatpanel2/IsParallel = "True"
s:Ge/flatpanel2/Type     = "TsBox"
s:Ge/flatpanel2/Parent   = "World"
d:Ge/flatpanel2/HLX      = 20 cm
d:Ge/flatpanel2/HLY      = 20 cm
d:Ge/flatpanel2/HLZ      = 1 mm
d:Ge/flatpanel2/TransX   = 0. m
d:Ge/flatpanel2/TransY   = 0. m
d:Ge/flatpanel2/TransZ   = 1. m
d:Ge/flatpanel2/RotX     = 0. deg
d:Ge/flatpanel2/RotY     = 0. deg
d:Ge/flatpanel2/RotZ     = 0. deg
s:Ge/flatpanel2/color    = "blue"
i:Ge/flatpanel2/XBins = 10
i:Ge/flatpanel2/YBins = 10
```

(The ”real-world” flatpanel has 40 x 40 resolution)

When we make a scorer, we just refer to this ”parallel world” componet:

```
s:Sc/SomeScorerName/Component = "flatpanel2"
```

How about time-of-flight?

What is phase-space scoring?

How to score time of flight of particles?

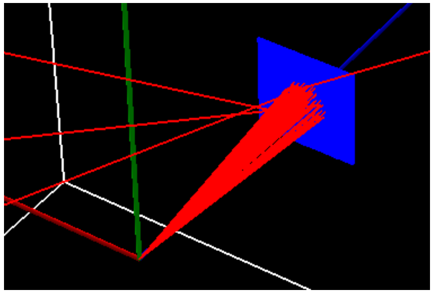
Answer: One possibility is to use a phasespace scorer.

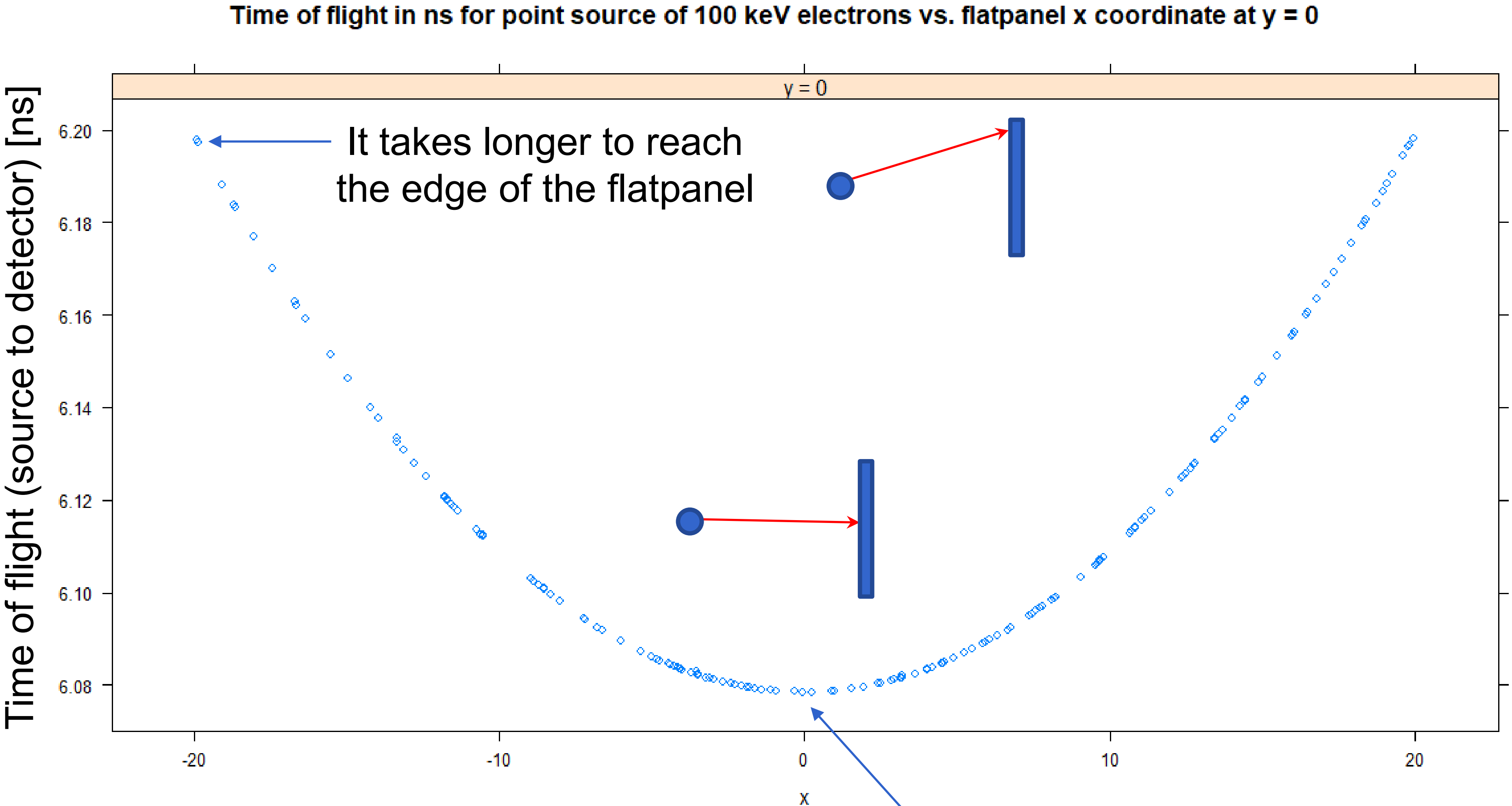
```
s:Sc/clanScorer3/Quantity = "Phasespace”
s:Sc/clanScorer3/Surface= "flatpanel/ZMinusSurface”
b:Sc/clanScorer3/IncludeTimeOfFlight = "True”
b:Sc/clanScorer3/IncludeRunID    = "True”
b:Sc/clanScorer3/IncludeEventID  = "True”
b:Sc/clanScorer3/IncludeTrackID  = "True”
b:Sc/clanScorer3/IncludeParentID = "True"
  # Track ID of parent particle
b:Sc/clanScorer3/IncludeCharge    = "True”
b:Sc/clanScorer3/IncludeCreatorProcess = "True”
b:Sc/clanScorer3/IncludeVertexInfo = "True"
  # Initial KE, Position and Momentum
b:Sc/clanScorer3/IncludeSeed = "True”
s:Sc/clanScorer3/OutputType = "ASCII”
b:Sc/clanScorer3/PropagateToChildren = "True”
s:Sc/clanScorer3/Component = "flatpanel2”
s:Sc/clanScorer3/IfOutputFileAlreadyExists = "Overwrite"
b:Sc/clanScorer3/OutputToConsole  = "False”
s:Sc/clanScorer3/OutputFile = Ge/World/Message + "Phasespace1"
```

Phasespace file with 28 columns:
#1: Position X [cm]
#2: Position Y [cm]
#3: Position Z [cm]
#4: Direction Cosine X
#5: Direction Cosine Y
#6: Energy [MeV]
#7: Weight
#8: Particle Type (in PDG Format)
#9: Flag to tell if Third Direction Cosine is Negative (1 means true)
#10: Flag to tell if this is the First Scored Particle from this History (1 means true)
#11: Time of Flight [ns]
#12: Run ID
#13: Event ID
#14: Track ID
#15: Parent ID
#16: Charge [e+]
#17: Creator Process Name
#18: Initial Kinetic Energy [MeV]
#19: Vertex Position X [cm] #20: Vertex Position Y [cm] #21: Vertex Position Z [cm]
#22: Initial Direction Cosine X #23: Initial Direction Cosine Y
#24: Initial Direction Cosine Z
#25: Seed Part 1 #26: Seed Part 2 #27: Seed Part 3 #28: Seed Part 4

Point source with 15 deg angle (not 5 deg as in the picture)

1m / 6.08 ns = 1.64E8 m/s (approx. 50% speed of light)





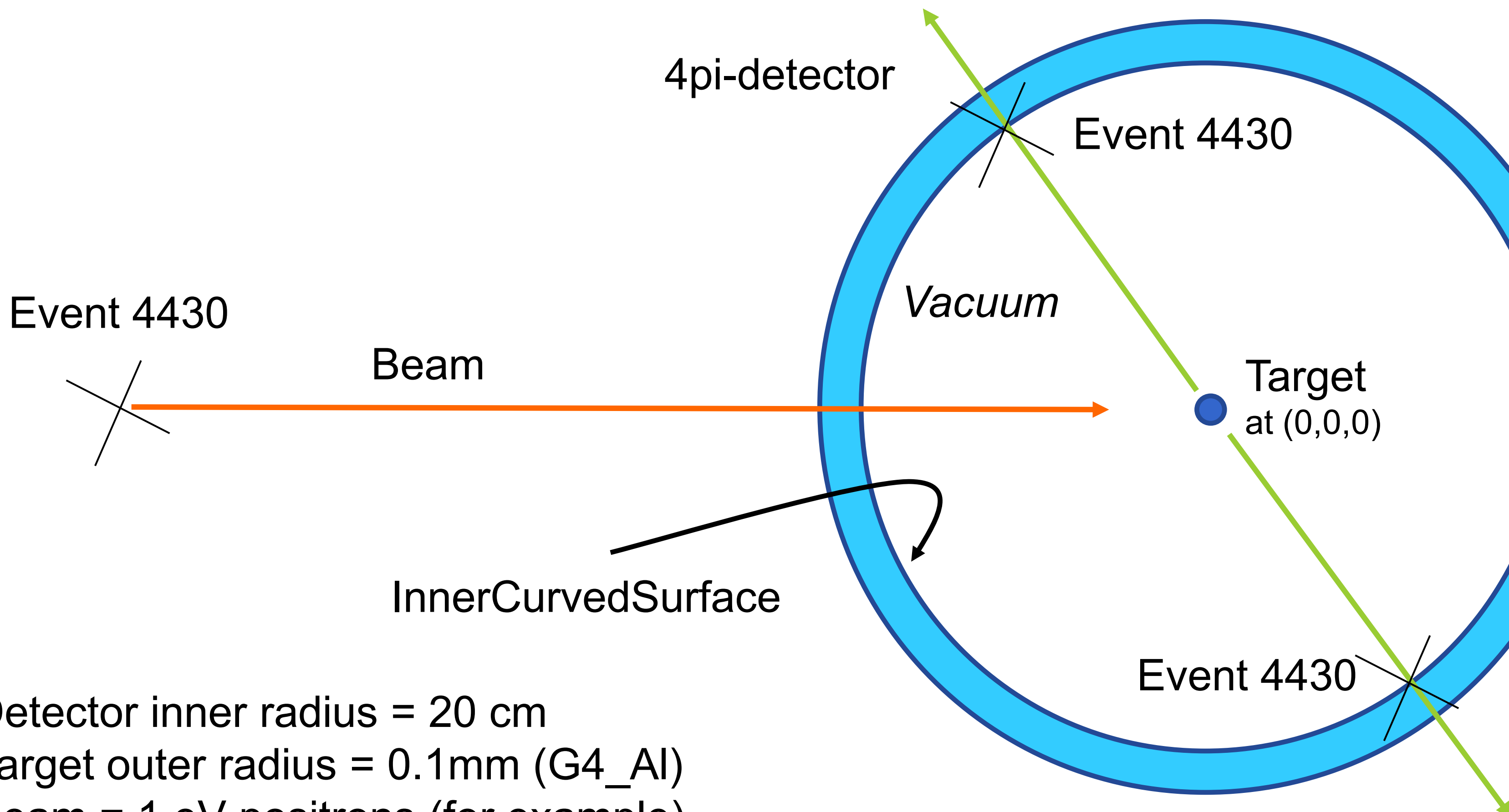
Shorest distance (center of flatpanel) is the fastest.

More about phase-space scoring

Using 4pi detector and phase space scoring

Each particle history from the beam source is associated with an event id. These are unique within each run.

The phasespace scorer can give us detailed information about the recorded hits, for example, at the inner curved surface of the detector.



Detector inner radius = 20 cm
Target outer radius = 0.1mm (G4_Al)
Beam = 1 eV positrons (for example)

Results from phasespace scorer in 4pi detector

Beam = positrons, target = Al

Run event id	x	y	z	MeV	Particle type	Creater process name	MeV.sum
<u>Shooting 1 eV positrons into target:</u>							
0-0	1.2537300	-5.880420	-19.07480000	0.510999	22	annihil	1.021998
0-0	-1.2537300	5.880420	19.07480000	0.510999	22	annihil	1.021998
0-1	6.4156800	-13.075500	13.70660000	0.510999	22	annihil	1.021998
0-1	-6.4156800	13.075500	-13.70660000	0.510999	22	annihil	1.021998
0-2	18.1159000	8.357020	1.40523000	0.510999	22	annihil	1.021998
0-2	-18.1159000	-8.357020	-1.40523000	0.510999	22	annihil	1.021998

Run 0, event 2

Note the perfect symmetry around (0,0,0). These annihilations are perfect back-to-back gammas.

Note, as an example, that the distance from (x,y,z) to (0,0,0):
((-18.1159000 cm)^2 +(-8.357020 cm)^2 +(-1.40523000 cm)^2)^0.5 = 20.000 cm
which verifies that these points are actually located on the detector sphere.

Note that the sum of energy for particles hitting the detector is always 1.021998 MeV.

Results from phasespace scorer in 4pi detector

Beam = positrons, target = Al

Run event id	x	y	z	MeV	Particle type	Creater proce	MeV.sum
Shooting 1 MeV positrons into target:							
0-412	-5.4949400	7.855230	17.552800	1.2307200	22	annihil	2.017131
0-412	9.0652200	-15.725900	8.397520	0.7864110	22	annihil	2.017131
0-882	-3.8491100	-7.544530	18.118100	1.3963700	22	annihil	2.006963
0-882	-7.3570100	18.521900	1.677870	0.6105930	22	annihil	2.006963
0-1882	1.3758200	3.614410	19.622500	1.5717700	22	annihil	2.005375
0-1882	-1.6320100	-18.778200	-6.686900	0.4336050	22	annihil	2.005375

Note that the sum of energy hitting the detector pr. event (MeV.sum) is now variable and always less than 2.021998 MeV. Why?

Answer: The positron loses a variable amount of energy in the target before annihilation. The secondaries from these interactions stay in the target and the secondaries are therefore not captured by the detector.

Note that the annihilation photons are not back-to-back in the frame of the laboratory coordinate system (lack of symmetry around (0,0,0)).

Results from phasespace scorer in 4pi detector

Beam = positrons, target = Al

Shooting 1 eV positrons into target.
Events with 3 detector hits:

Run event id	x	y	z	MeV init	MeV	Particle type	Creater process name	MeV sum
0-115	-1.54866000	-0.868451	-19.921000	0.5109990	0.5109990	22	annihil	0.94165
0-115	-3.19828000	-19.569600	-2.607920	0.5109990	0.2348890	22	annihil	0.94165
0-115	2.51310000	-1.207900	19.804700	0.2760280	0.1957640	11	compt	0.94165
0-452	8.47510000	14.092200	-11.383500	0.5109990	0.5109990	22	annihil	1.00087
0-452	-3.49529000	-18.041100	-7.893080	0.5109990	0.3317510	22	annihil	1.00087
0-452	-3.91598000	-6.506080	18.502300	0.1791660	0.1581270	11	compt	1.00087
0-947	18.88940000	-5.398080	3.748680	0.5109990	0.2034750	22	annihil	0.95168
0-947	-16.03400000	3.532880	11.420600	0.3074050	0.2372110	11	compt	0.95168
0-947	13.90580000	3.755140	-13.875400	0.5109990	0.5109990	22	annihil	0.95168

Note that the annihilation photons that underwent Compton scattering are classified as annihilation photons. Only the electrons from the Compton interactions, are classified as being created by the Compton.

Phasespace scorer in 4pi detector

Topas parameters

```
# The 4pi-detector
s:Ge/detector/Type     = "TsSphere"
s:Ge/detector/Material = "G4_Galactic"
s:Ge/detector/Parent   = "World"
d:Ge/detector/RMin     = 20.0 cm
d:Ge/detector/RMax     = 20.1 cm
d:Ge/detector/TransX   = 0. m
d:Ge/detector/TransY   = 0. m
d:Ge/detector/TransZ   = 0. m
d:Ge/detector/RotX     = 0. deg
d:Ge/detector/RotY     = 0. deg
d:Ge/detector/RotZ     = 0. deg
s:Ge/detector/color    = "blue"

# The target
s:Ge/target/Type     = "TsSphere"
s:Ge/target/Material = "G4_Al"
s:Ge/target/Parent   = "world"
d:Ge/target/RMax     = 0.01 cm
d:Ge/target/TransX   = 0. m
d:Ge/target/TransY   = 0. m
d:Ge/target/TransZ   = 0. m
d:Ge/target/RotX     = 0. deg
d:Ge/target/RotY     = 0. deg
d:Ge/target/RotZ     = 0. deg
s:Ge/target/color    = "blue"
```

Phasespace scorer in 4pi detector

Topas parameters

```
# Beam
s:So/clanBeam/Type                = "Beam"
s:So/clanBeam/Component           = "clanBeamPosition"
s:So/clanBeam/BeamParticle        = "e+"
d:So/clanBeam/BeamEnergy          =  1 eV
u:So/clanBeam/BeamEnergySpread = 0.0
s:So/clanBeam/BeamPositionDistribution = “Flat"
s:So/clanBeam/BeamPositionCutoffShape  = "Rectangle"
dc:So/clanBeam/BeamPositionCutoffX = 0.000001 mm
dc:So/clanBeam/BeamPositionCutoffY = 0.000001 mm
dc:So/clanBeam/BeamPositionSpreadX = 0.000001 mm
dc:So/clanBeam/BeamPositionSpreadY = 0.000001 mm
s:So/clanBeam/BeamAngularDistribution = "Flat"
dc:So/clanBeam/BeamAngularCutoffX = 0.000001 deg
dc:So/clanBeam/BeamAngularCutoffY = 0.000001 deg
dc:So/clanBeam/BeamAngularSpreadX = 0.000001 deg
dc:So/clanBeam/BeamAngularSpreadY = 0.000001 deg
i:So/clanBeam/NumberOfHistoriesInRandomJob = 0
```

Phasespace scorer in 4pi detector

Topas parameters

```
# Phasespace scorer
s:Sc/clanScorer3/Quantity = "Phasespace"
s:Sc/clanScorer3/Component = "detector"
s:Sc/clanScorer3/Surface  = "detector/InnerCurvedSurface"
s:Sc/clanScorer3/OnlyIncludeParticlesGoing = "In"

b:Sc/clanScorer3/IncludeTimeOfFlight   = "True"
b:Sc/clanScorer3/IncludeRunID          = "True"
b:Sc/clanScorer3/IncludeEventID        = "True"
b:Sc/clanScorer3/IncludeTrackID        = "True"
b:Sc/clanScorer3/IncludeParentID       = "True"
b:Sc/clanScorer3/IncludeCharge         = "True"
b:Sc/clanScorer3/IncludeCreatorProcess = "True"
b:Sc/clanScorer3/IncludeVertexInfo     = "True"
b:Sc/clanScorer3/IncludeSeed           = "True"

s:Sc/clanScorer3/OutputType = "ASCII"
b:Sc/clanScorer3/PropagateToChildren = "True"
s:Sc/clanScorer3/IfOutputFileAlreadyExists = "Overwrite"
b:Sc/clanScorer3/OutputToConsole = "False"
s:Sc/clanScorer3/OutputFile = Ge/World/Message + "Phasespace1"
```

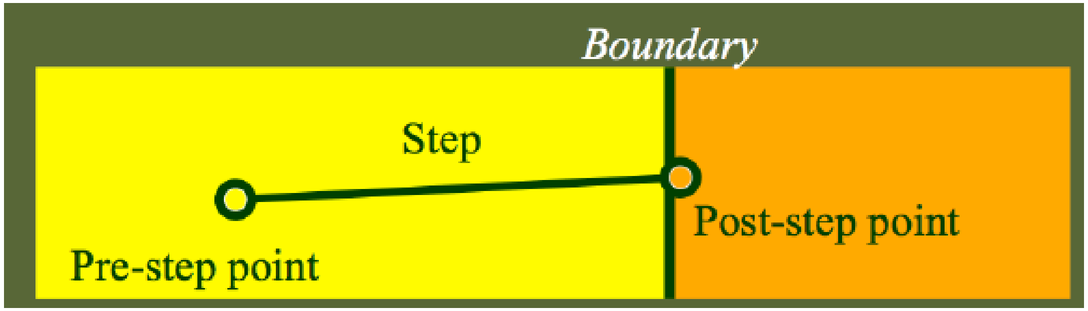
GEANT4 terminology

- **Events** are the basic units of a simulation (G4Event)
- At the beginning of an event, **primary tracks** are generated and stored in a **stack**
- The track is a snapshot of a **particle**, and it keeps its current information: energy, momentum, etc.
- GEANT4 gets a track from the stack and follows it in the geometry, until it exits the world or stops
  - If **secondary tracks** are produced in this process, they are also stored in the stack
  - When the stack is empty the event is completed
- A **run** is a collection of events all with the same detector setup and physics settings

From: 1st LIP Introductory Course on GEANT4, Feb. 2020, Universidade do Minho

GEANT4 terminology

- Tracks are divided in **steps**
- A new step occurs every time the particle crosses a border or has an interaction
- A step has two points (**pre-step** and **post-step**) and G4Step stores information about both and the deltas (e.g. energy loss in the step)
- If a step is limited by a volume boundary, the post-step point is physically at the border, and associated with the next logical volume



From: 1st LIP Introductory Course on GEANT4, Feb. 2020, Universidade do Minho

How to score a fluence spectrum differential in energy?

Fluence spectra scoring

Unless you score the fluence in vacuum, you normally need to select the ”PreStep” energy for binning:

```
i:Sc/MyScorer/EBins = 10
# defaults to 1, that is, un-binned

d:Sc/MyScorer/EBinMin = 0. MeV
# defaults to zero

d:Sc/MyScorer/EBinMax = 100. MeV
# must be specified if EBins is greater than 1

s:Sc/MyScorer/EBinEnergy = "PreStep"
# "IncidentTrack" # "IncidentTrack", "PreStep" or
# "DepositedInStep"
```

Note that if you create particles inside your scoring volume (volume source), then they have no incident energy, and they will not be considered if you select ”IncidentTrack” for binning. This is another reason to select `”PreStep”`.

How to score kerma?

Topas manual (3.9) section 12.2.1

Cuts do not affect all processes, but only those listed below:
- *Energy thresholds for gamma are used in Bremsstrahlung*
- *Energy thresholds for electrons are used in ionization and e+e- pair production processes Energy thresholds for positrons are used in e+e- pair production process*
- *Energy thresholds for gamma and electrons are **used optionally** in all discrete processes*

– Photoelectriceffect
– Compton
– gamma conversion
- *Energy thresholds for protons are used in processes of elastic scattering for hadrons and ions defining the threshold for kinetic energy of nuclear recoil*

Unknown what this means or how this is controlled

BE CAREFUL HERE: This does not work in general!!!!
We cannot simply force all electrons **not** to be transported if they have an energy below say 10 MeV (specified by an equivalent range in the medium):

```
d:Ph/Default/cutforelectron = 10 m
```

So, unfortunately, we cannot score kerma using the dosetomedium scorer by simply stopping electrons from moving after photons have undergone, for example, photoelectric effect or Compton scattering.

Collision-kerma scorer

```
##### Collion-kerma scoring using the TLE (see paper by Berumen et al. (2020))
s:Sc/kerma/Quantity = "TrackLengthEstimator"
b:Sc/kerma/PropagateToChildren = "True"

sv:Sc/kerma/Report = 5 "Count_In_Bin" "Sum" "Mean" "Standard_Deviation" "Histories"
s:Sc/kerma/InputFile                      = "Muen.dat"
s:Sc/kerma/Component                      = "centerrod"
b:Sc/kerma/OutputToConsole                = "False"
s:Sc/kerma/IfOutputFileAlreadyExists      = "Overwrite"
s:Sc/kerma/OutputType                     = "csv"
s:Sc/kerma/OutputFile                     = Ge/World/Message + "DoseScorer2"
sv:Sc/kerma/OnlyIncludeParticlesNamed = 1 "gamma"
```

You need to copy this file from the examples/Brachytherapy folder (or make a direct link)

DO NOT FORGET THIS!

Essentially, this is just the photon fluence times the mass energy absorption coefficient (μ_{en}/ρ) from the `Muen.dat` file.

Berumen et al. (2020):
"Validation of the TOPAS Monte Carlo toolkit for HDR brachytherapy simulations"
Medical Physics

The TLE technique approximates the absorbed dose as electronic (collisional) kerma. For a photon traversing a voxel, the absorbed dose is

$$D = \Phi\, E\, \frac{\mu_{en}}{\rho} = \frac{L}{V}\, E\, \frac{\mu_{en}}{\rho},$$

where L is the track length (the distance traveled in the voxel), V is the voxel volume, E is the photon energy, and μ_{en}/ρ is the mass energy absorption coefficient.

The `Muen.dat` file contains photon interaction data.
The source of data is not clear.

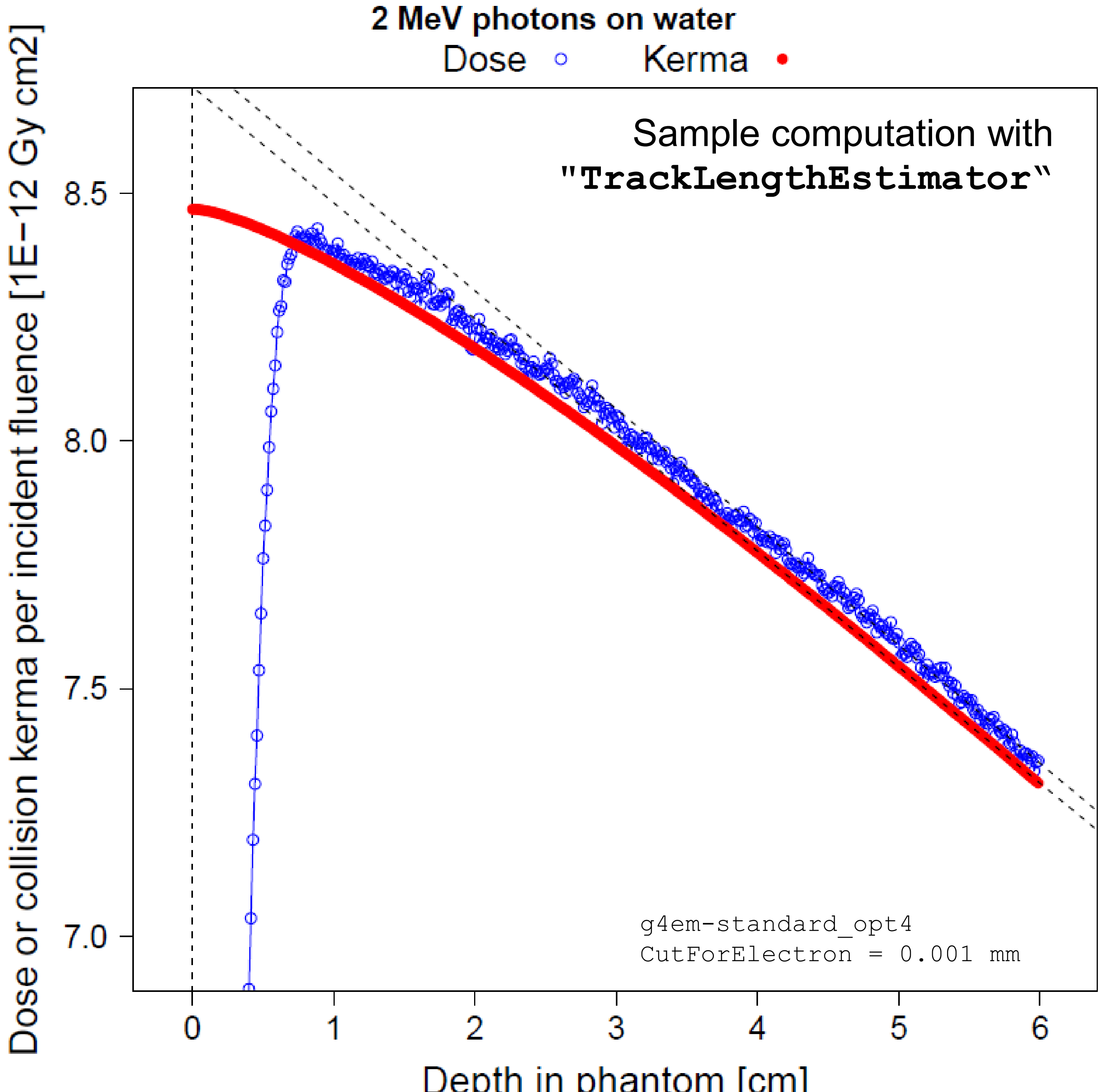
```
1 36
1.00000E-03 7.217E+00 6.820E+00
1.50000E-03 2.148E+00 1.752E+00
2.00000E-03 1.059E+00 6.643E-01
3.00000E-03 5.612E-01 1.693E-01
4.00000E-03 4.546E-01 6.549E-02
5.00000E-03 4.193E-01 3.278E-02
6.00000E-03 4.042E-01 1.996E-02
8.00000E-03 3.914E-01 1.160E-02
1.00000E-02 3.854E-01 9.849E-03
...
1.00000E-01 2.944E-01 4.063E-02
1.50000E-01 2.651E-01 4.813E-02
2.00000E-01 2.429E-01 5.254E-02
3.00000E-01 2.112E-01 5.695E-02
4.00000E-01 1.893E-01 5.860E-02
5.00000E-01 1.729E-01 5.900E-02
6.00000E-01 1.599E-01 5.875E-02
8.00000E-01 1.405E-01 5.739E-02
1.00000E+00 1.263E-01 5.556E-02
1.25000E+00 1.129E-01 5.311E-02
...
1.00000E+01 3.254E-02 2.247E-02
1.50000E+01 2.539E-02 1.837E-02
2.00000E+01 2.153E-02 1.606E-02
```

The data to the left is the initial part of the file. The data appears to be in the format:

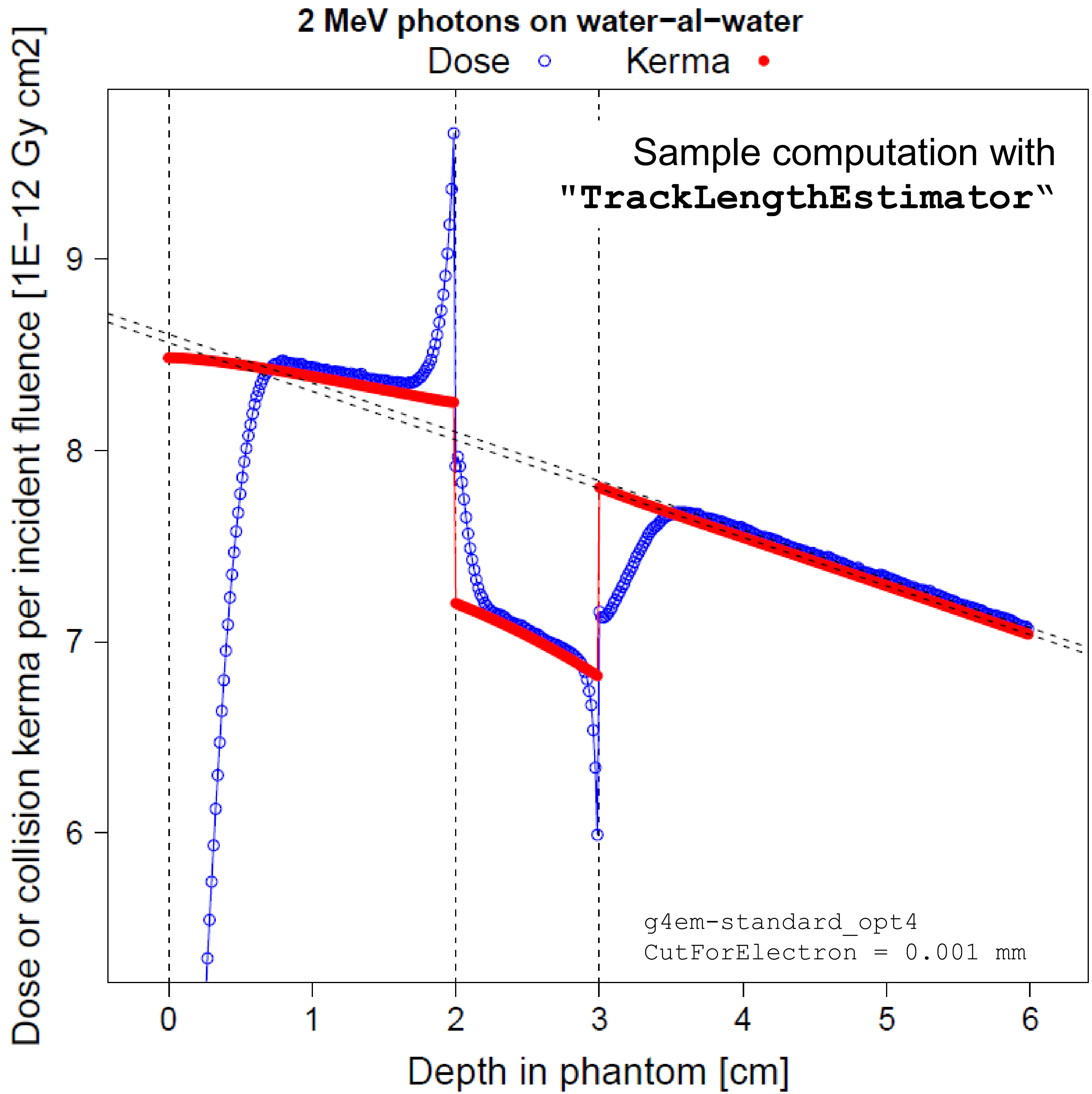
<MeV> <μ/ρ> <μ_{en}/ρ>

for hydrogen (Z = 1 in the (1, 36) opening line) with 36 data points in the range from 1 keV to 20 MeV.

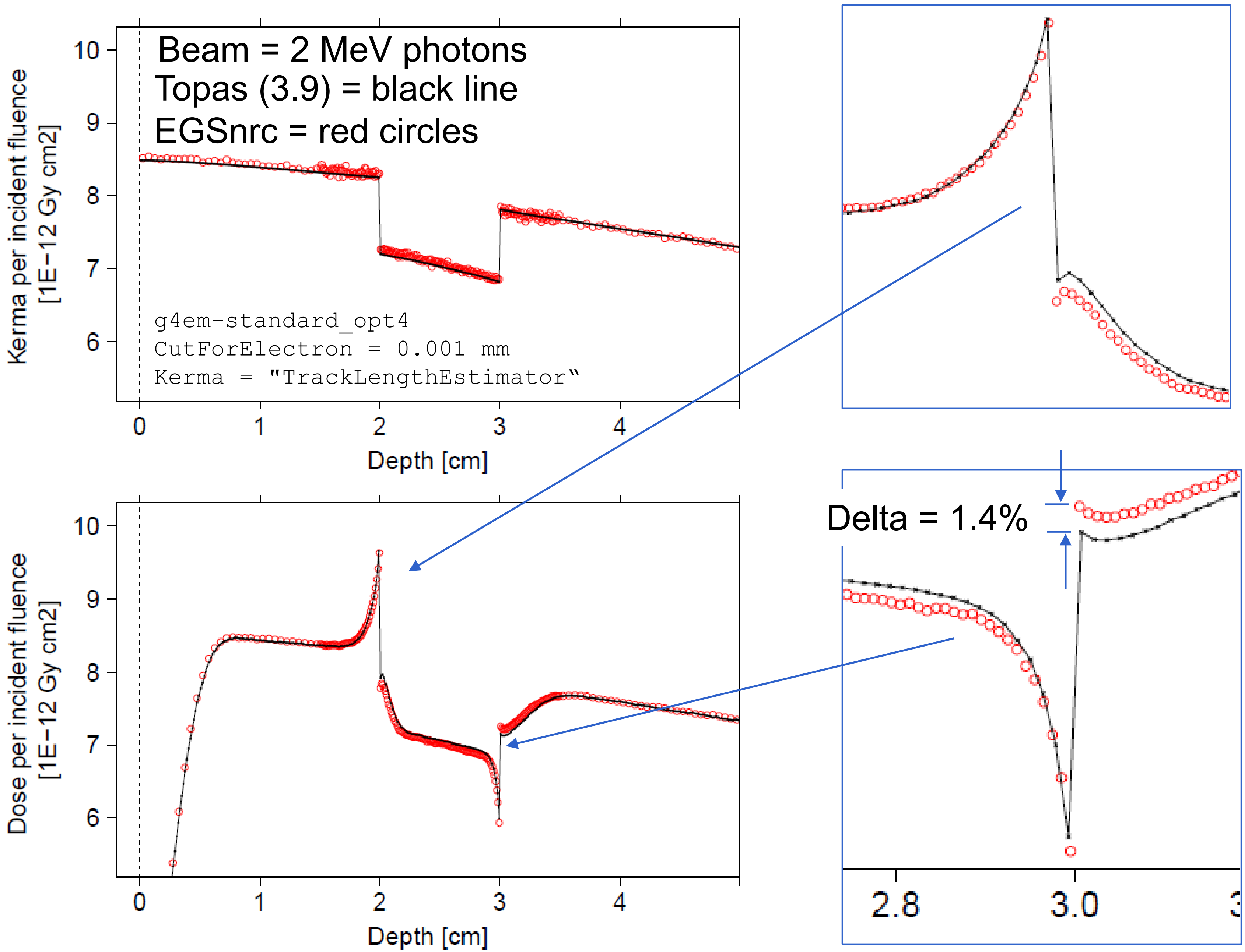
If, so, then the file contains data for elements 1 to 92.



2 MeV photons on water
Dose
Kerma
Sample computation with
"TrackLengthEstimator"
g4em-standard_opt4
CutForElectron = 0.001 mm
Dose or collision kerma per incident fluence [1E−12 Gy cm2]
8.5
8.0
7.5
7.0
0
1
2
3
4
5
6
Depth in phantom [cm]


2 MeV photons on water-al-water
Dose
Kerma
Sample computation with
"TrackLengthEstimator"
g4em-standard_opt4
CutForElectron = 0.001 mm
Dose or collision kerma per incident fluence [1E−12 Gy cm2]
Depth in phantom [cm]
0
1
2
3
4
5
6
7
8
9

Topas vs. EGSnrc for the water-aluminium-water interface



Topas:

How to represent the spectral distribution of photons from a Varian medical linac ?

The Topas-VarianBeamAR.txt file on GitHub

Using the data in Table 5 of the Ali & Rogers (2012) paper:

IOP PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. 57 (2012) 31–50 doi:10.1088/0031-9155/57/1/31

Functional forms for photon spectra of clinical linacs

E S M Ali and D W O Rogers

Carleton Laboratory for Radiotherapy Physics, Department of Physics, Carleton University,
1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada

E-mail: eali@physics.carleton.ca and drogers@physics.carleton.ca

Received 26 May 2011, in final form 18 September 2011
Published 29 November 2011
Online at stacks.iop.org/PMB/57/31

Simple histograms representing the
Varian Clinac 4 MV, 6 MV, 10 MV, 15 MV and 18 MV

The spectra are in the file: Topas-VarianBeamAR.txt

availible here:

https://github.com/claus-e-andersen/topas

Use of the Topas-VarianBeamAR.txt file

1. Put the following text in your parameter file.

2. Copy the `Topas-VarianBeamAR`.txt file to the folde of your parameter file.

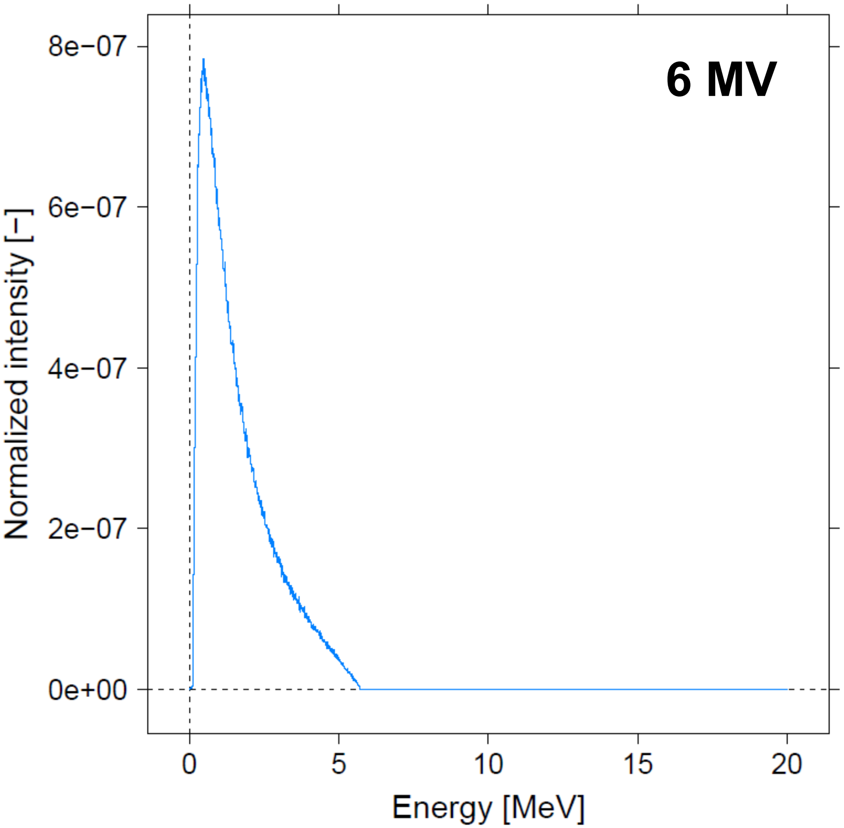
3. Modify the source name and select the beam quality as indicated below:

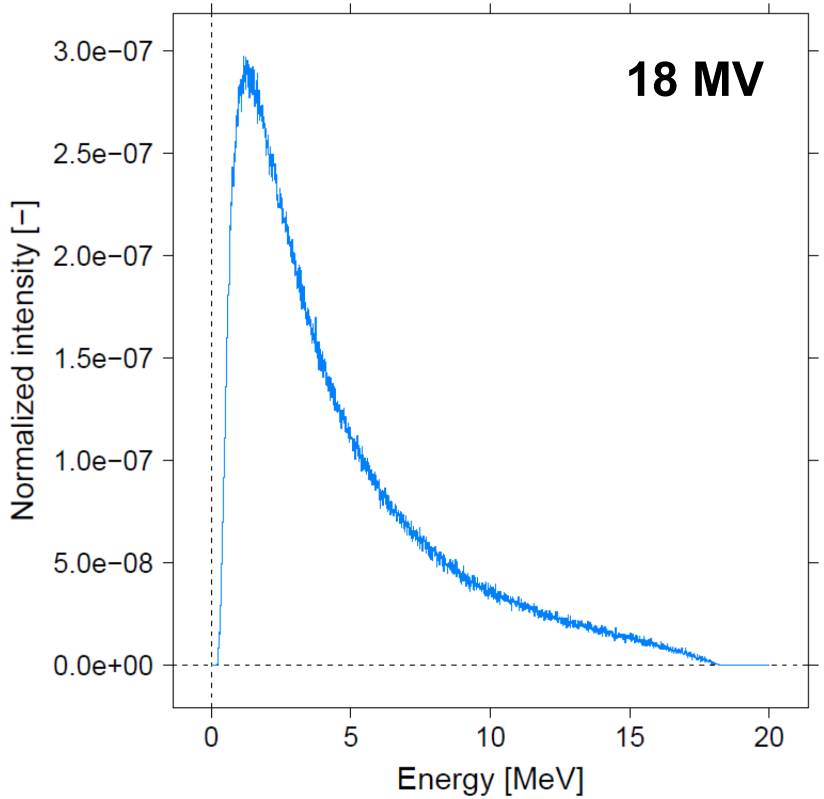
```
includeFile = Topas-VarianBeamAR.txt

s:So/clanBeam/BeamEnergySpectrumType = "Continuous"
# None, Continuous or Discrete

# Code for selection of spectra:
VarianBeamxxMV where xx = 04, 06, 10, 15, or 18

dv:So/clanBeam/BeamEnergySpectrumValues =
                                     So/VarianBeam04MV/BeamEnergySpectrumValues MeV

uv:So/clanBeam/BeamEnergySpectrumWeights =
                                     So/VarianBeam04MV/BeamEnergySpectrumWeights
```

Write the specific name
of your gamma source here.

This is where you select the beam quality

Topas-VarianBeamAR.txt file examples





How to make radioactivity in Topas?

Radioactive decay

Select a proper physics list:

```
sv:Ph/Default/Modules = 7 "g4em-standard_opt4"
"g4h-phy_QGSP_BIC_HP" "g4decay" "g4ion-binarycascade"
"g4h-elastic_HP" "g4stopping" "g4radioactivedecay"
```

If you shoot neutrons into a big lump of aluminum sitting in a 4pi-detector phasespace scorer, you can see if you get any photons out that were created by the process "`RadioactiveDecayBase`".

If it works, you may want to limit the scorer only to record photons from this process.

From their initial kinetic energy, you can see if they are the same as you measured (1.7 MeV) and from the time-of-flight data, you can see if they arrive at the detector as expected from exponential decay and the half-life specific for Al-28.

Ressources

TOPAS MC
http://www.topasmc.org/

TOPAS MC Users - Google Grupper
https://groups.google.com/g/topas-mc-users
(require registration)

Geant4 Forum (cern.ch)
https://geant4-forum.web.cern.ch/

List of materials:
Geant4 Material Database — Book For Application Developers 11.1 documentation (cern.ch)
https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/Appendix/materialNames.html

Ressources on Github

topasmc (github.com)
https://github.com/topasmc

https://github.com/jschuemann/extensions

"Dirty dose extension etc.:"
Villadslj/Topas-Extension: Different kind of TOPAS extensions (github.com)

Varian spectra:
claus-e-andersen/TopasTools: Tools for Topasmc (Topas Monte-Carlo) modelling (github.com)
https://github.com/claus-e-andersen/TopasTools