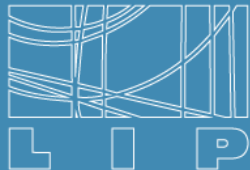


SIMULATION WITH TOPAS

PRACTICAL WORKSHOP

LIP Internship Program 2026 - Lectures and Tutorials Week

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LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS



Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

July 10, 2026

TOol for PArticle Simulation



- A Geant4-based Monte Carlo simulation.
- Easy-to-use:
 - The simulation is controlled by a parameter file.
 - It is possible assemble and control a rich library of simulation objects (geometry components, particle sources, scorers, etc.) with no need to write C++ code.
- Focus on medical applications.
- The users can implement their own simulation objects in C++ code and add them to TOPAS via an extension mechanism.
- Userguide: <https://topas.readthedocs.io/en/latest/index.html>

TOPAS Parameter files

```
# Water Box with 10*10*40 cm3
s:Ge/MyBox/Type      = "TsBox"
s:Ge/MyBox/Material  = "G4_WATER"
s:Ge/MyBox/Parent    = "World"
d:Ge/MyBox/HLX       = 5 cm
d:Ge/MyBox/HLY       = 5 cm
d:Ge/MyBox/HLZ       = 20 cm
```

Parameters files are simple text files made up of lines of key/value pairs.

The order of lines within a parameter file does not matter.

Parameter_Type : **Parameter_Name** = **Parameter_Value** #Optional comment

Tells TOPAS what **type of data** will be in this parameter:

d for Dimensioned Double

u for Unitless Double

i for Integer

b for Boolean

s for String

dv for Dimensioned Double Vector

similarly, for uv, iv, bv and sv

Can be almost any string, but there are **prefix conventions** to keep things clear:

Ma/ for Materials

El/ for Elements

Is/ for Isotopes

Ge/ for Geometry Components

So/ for Particle Sources

Ph/ for Physics

Parameter names are not case sensitive.

Vr/ for Variance Reduction

Sc/ for Scoring

Gr/ for Graphics

Tf/ for Time Features

Ts/ for TOPAS overall control

TOPAS Parameter files

```
d:Ge/Phantom/HLX          = 10. cm      # Dimensioned Double
i:Sc/DoseScorer/ZBins      = 100          # Integer
b:Sc/DoseScorer/Active     = "True"       # Boolean
s:Ge/Phantom/Material      = "G4_WATER"   # String

dv:Ge/RMW_Track1/Angles    = 4 69.1 92.2 111.0 126.0 deg  # Dimensioned Double Vector
uv:Ma/Phantom_Plastic/Fractions = 3 0.05549 0.75575 0.18875  # Unitless Double Vector
iv:Gr/Color/yellow        = 3 225 255 0          # Integer Vector
bv:Tf/ScoringOnOff/Values  = 4 "true" "false" "true" "false" # Boolean Vector
sv:Ma/MyPlastic/Components = 3 "Hydrogen" "Carbon" "Oxygen" # String Vector
```

Relative Parameters

- TOPAS supports “relative parameters”, wherein one parameter may be set relative to another:

`s:Ge/Phantom/Material = SomeOtherParameterName`

- With relative dimensioned double parameters, we must insist that a unit be included on the right side of the expression:

`d:Ge/Phantom/HLX = SomeOtherParameterName cm`

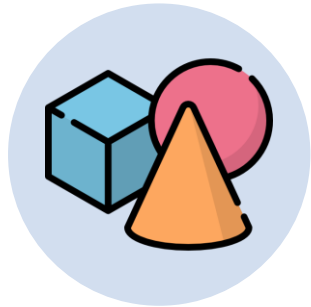
- TOPAS has a grammar for operations such as adding or multiplying parameters:

`d:Ge/Compensator/TransZ = Ge/Aperture/DistalEdge + Ge/Compensator/HLZ mm`

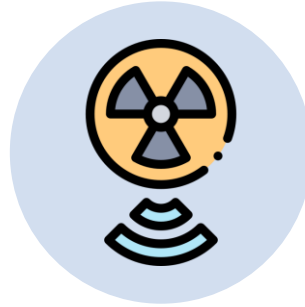
Note that there must be a space before and after the plus sign.

The complete set of allowed syntax for any one parameter line is shown [here](#).

TOPAS Parameter files



GEOMETRY



SOURCE



PHYSICS



SCORER

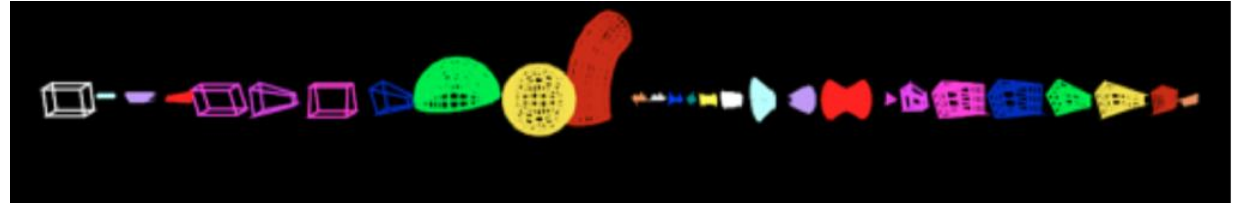


VISUALIZATION

Geometry Components

- TOPAS includes all the standard Geant4 solids

TsSphere, TsBox, TsCylinder, G4CutTubs, G4Cons, G4Para, ...



- Each one of them has its own set of required parameters:

TsBox	TsSphere	TsCylinder
HLX, HLY and HLZ*	RMin, RMax, DPhi and SPhi	HL, RMin, RMax, DPhi and SPhi

All parameters, including optional ones, for all the Geant4 solids, can be found in this [example](#).

* Half length

- It is possible built some complex things just from combinations of the Generic Components.
- TOPAS also has more specialized Components as a Range Modulator Wheel and a Multi Leaf Collimator. Usage is best learned by studying the relevant examples parameter files included in TOPAS.

Geometry Components

- All Geometry Components must have at least the following parameters:

```
s:Ge/MyComponent/Type = "TsBox"
```

```
s:Ge/MyComponent/Parent = "World"
```

```
d:Ge/MyComponent/TransX = 0.0 cm #defaults to 0
```

```
d:Ge/MyComponent/TransY = 0.0 cm #defaults to 0
```

```
d:Ge/MyComponent/TransZ = -2. cm #defaults to 0
```

```
d:Ge/MyComponent/RotX = 0.0 deg #defaults to 0
```

```
d:Ge/MyComponent/RotY = 0.0 deg #defaults to 0
```

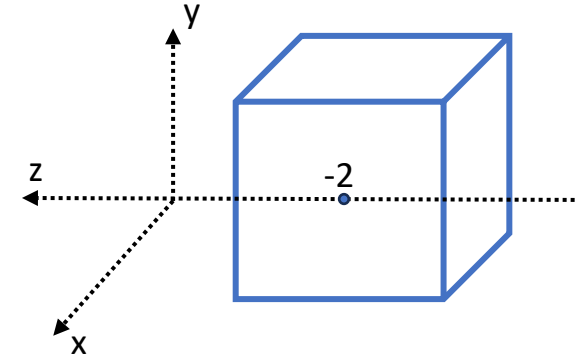
```
d:Ge/MyComponent/RotZ = 0.0 deg #defaults to 0
```

```
s:Ge/MyComponent/Material = "Air"
```

Translation
Parameters

Rotation
Parameters

Position of the component
in the coordinate system of
its parent component.



When building geometry, activate overlap checking. It has a speed cost at initialization, so if you're confident there are no overlaps, you can turn it off.

```
b:Ge/CheckForOverlaps = "False"
```

Materials and Isotopes

- Pre-defined materials: Vacuum, Nickel, Aluminum, ... (list in [here](#))

- You are free to define additional materials:

```
sv:Ma/Air/Components = 4 "Carbon" "Nitrogen" "Oxygen" "Argon" #names of elements
uv:Ma/Air/Fractions = 4 0.000124 0.755268 0.231781 0.012827 #fractions of elements
d:Ma/Air/Density = 1.2048 mg/cm3
d:Ma/Air/MeanExcitationEnergy = 85.7 eV
```

- You can also create a new mixture from a combination of other materials.

```
b:Ma/MyMixture/BuildFromMaterials = "True"
sv:Ma/MyMixture/Components = 2 "G4_WATER" "Air"
uv:Ma/MyMixture/Fractions = 2 .5 .5
d:Ma/MyMixture/Density = .5 g/cm3
```

- To define an isotope you must specifying Z, N and A:

```
i:Is/U235/Z = 92
i:Is/U235/N = 235
d:Is/U235/A = 235.01 g/mole
```

Particle Sources

- Different types of particle sources, each with many options:

`s:So/MySource/Type = "Beam" #Beam, Isotropic, Distributed, Volumetric or PhaseSpace`

- The source position can be defined by the user, and it must be associated with a geometry component.

`s:So/MySource/Component = "BeamPosition"`

- Particle names can take the following forms (case does not matter):

`s:So/MySource/BeamParticle = "proton"`

- A simple string such as “proton”, “e-”, “gamma”, “He3”;
- A string describing an ion with arguments Z, A, and optionally Charge, such as: “Genericlon(6,12,6)”;
- An integer PDG ID code;

Particle Sources

Beam Source

- You must define the beam energy and spread:

```
d:So/MySource/BeamEnergy = 169.23 MeV
```

```
u:So/MySource/BeamEnergySpread = 0.757504
```

- You can provide an energy spectrum instead of a fixed energy, by defining the energies and weights:

```
s:So/MySource/BeamEnergySpectrumType = "Continuous" # or "Discrete"
```

```
dv:So/MySource/BeamEnergySpectrumValues = 3 50. 100. 150. MeV
```

```
uv:So/MySource/BeamEnergySpectrumWeights = 3 .20 .60 .20
```

- The beam shape can be further described by a set of parameters that control the position distribution of the start of the beam and by a set of parameters that control how the beam spreads out from that start position.

- To define how many particles are generated, you must do:

```
i:So/MySource/NumberOfHistoriesInRun = 100
```

BeamAngular

Distribution, CutoffX,
CutoffY, SpreadX and SpreadY

BeamPosition

Distribution, CutoffShape,
CutoffX, CutoffZ, SpreadX
and SpreadY

Particle Sources

Isotropic, Distributed and Volumetric Sources

- **Isotropic** sources emit particles uniformly from the center of the specified component.
- **Distributed** source represents radioactive material randomly distributed within other material.

```
s:So/MySource/Component = "DemoSphere"  
i:So/MySource/NumberOfHistoriesInRun = 5  
i:So/MySource/NumberOfSourcePoints = 4
```

- **Volumetric** source emit particles from randomly sampled starting positions from within the radioactive volume of a given component. This source type has been designed for Brachytherapy applications.

```
s:So/MySource/Type = "Volumetric"  
s:So/MySource/Component = "ActiveSource"  
s:So/MySource/ActiveMaterial = "G4_Ir"
```

The energies and species of the emitted particles can be specified using the usual parameters as BeamParticle, BeamEnergy and BeamEnergySpread.

Scorers

- There are two basic classes of scorers: Volume and Surface Scorers

You must indicate the relevant Component

`s:Sc/MyScorer/Component = "Phantom"`

Quantity	
DoseToMedium	EnergyFluence
DoseToWater	StepCount
DoseToMaterial	OpticalPhotonCount
TrackLengthEstimator	OriginCount
AmbientDoseEquivalent	Charge
EnergyDeposit	EffectiveCharge
Fluence	ProtonLET

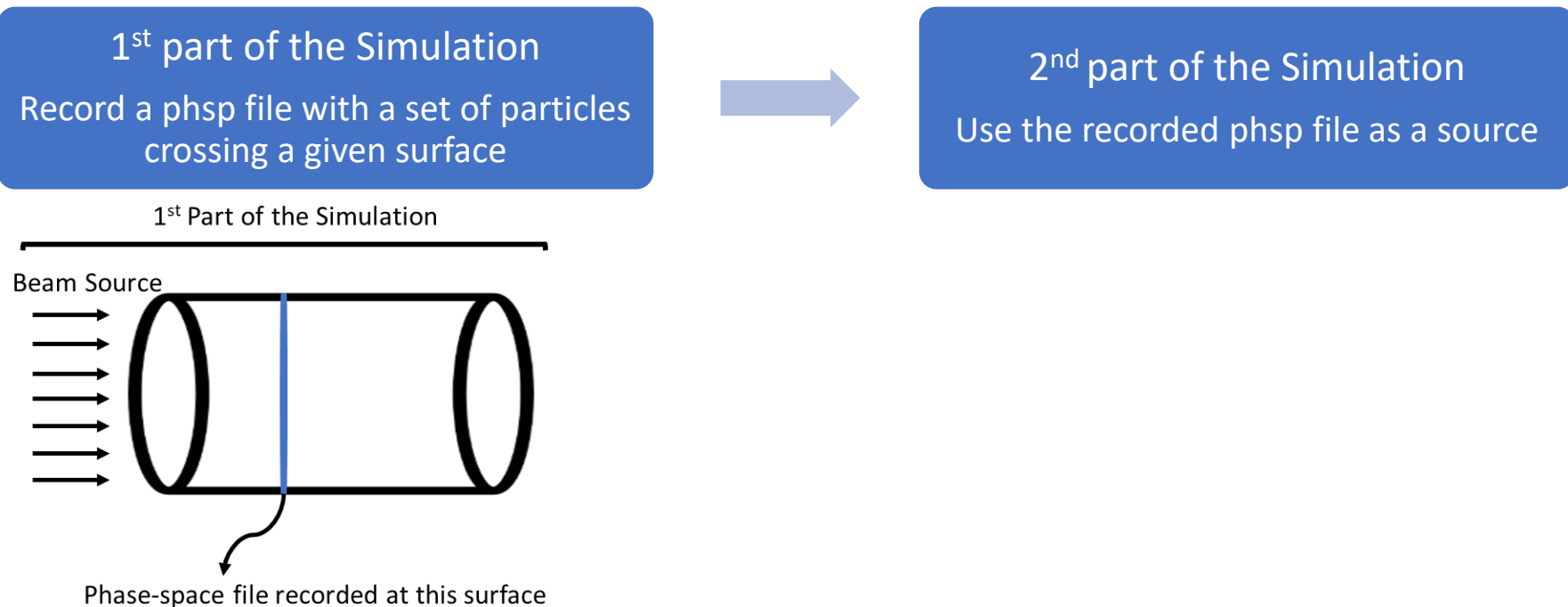
You must indicate the relevant Component and Surface name

`s:Sc/MyScorer/Surface="Phantom/ZMinusSurface"`

Quantity	
SurfaceTrackCount	SurfaceCurrent
PhaseSpace	

Phase Space

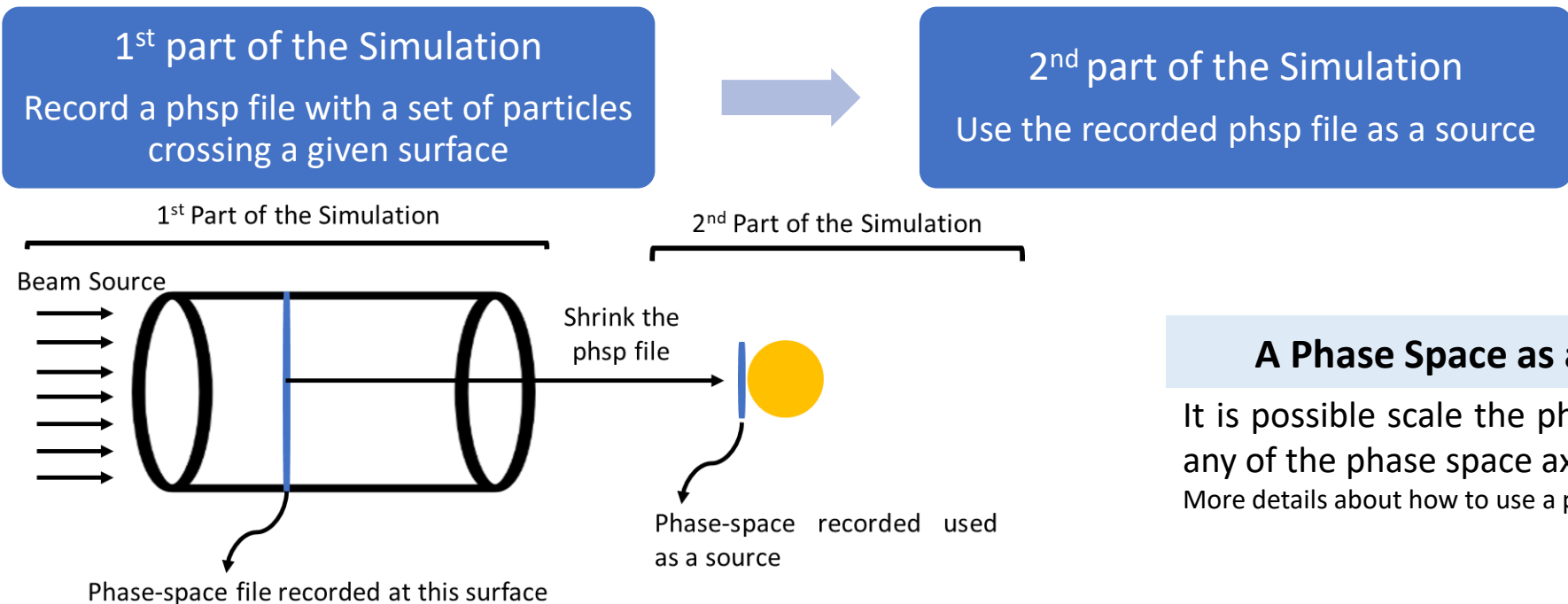
- This type of scorer enables separating two parts of a simulation and can be used to transfer sets of particles among different codes.



- Four formats for Phase Space are supported: Binary, ASCII, Limited or ROOT.

Phase Space

- This type of scorer enables separating two parts of a simulation and can be used to transfer sets of particles among different codes.



A Phase Space as a particle source

It is possible scale the phsp position and invert any of the phase space axes.

More details about how to use a phsp file as a source [here](#).

- Four formats for Phase Space are supported: Binary, ASCII, Limited or ROOT

Physics

- A physics list specifies what particles and physics processes are defined, plus various cuts and options.
- You can choose from two general types of physics lists:
 - Reference Physics Lists are pre-made, complete lists provided by Geant4.
 - **Modular Physics Lists** are lists where you mix and match a set of modules to create a customized complete list.

```
sv:Ph/MyPhysics/Modules = 1 "g4em-livermore"  
d:Ph/MyPhysics/CutForAllParticles = 0.05 mm  
b:Ph/MyPhysics/Fluorescence = "True"  
b:Ph/MyPhysics/Auger = "True"  
b:Ph/MyPhysics/AugerCascade = "True"  
b:Ph/MyPhysics/PIXE = "True"
```

TOPAS Module Name	Geant4 Class Name
g4em-livermore	G4EmLivermorePhysics
g4em-penelope	G4EmPenelopePhysics
g4radioactivedecay	G4RadioactiveDecayPhysics
g4em-dna*	G4EmDNAPhysics

[List of Available Modules](#)

*Only for water
Goes down to 10. eV

References

Perl J, Shin J, Schumann J, Faddegon B, Paganetti H. TOPAS: an innovative proton Monte Carlo platform for research and clinical applications. Med Phys. 2012; 39(11):6818-37.

Faddegon B, Ramos-Mendez J, Schuemann J, McNamara A, Shin J, Perl J, Paganetti H, The TOPAS Tool for Particle Simulation, a Monte Carlo Simulation Tool for Physics, Biology and Clinical Research, Physica Medica, doi:10.1016/j.ejmp.2020.03.019

Questions?

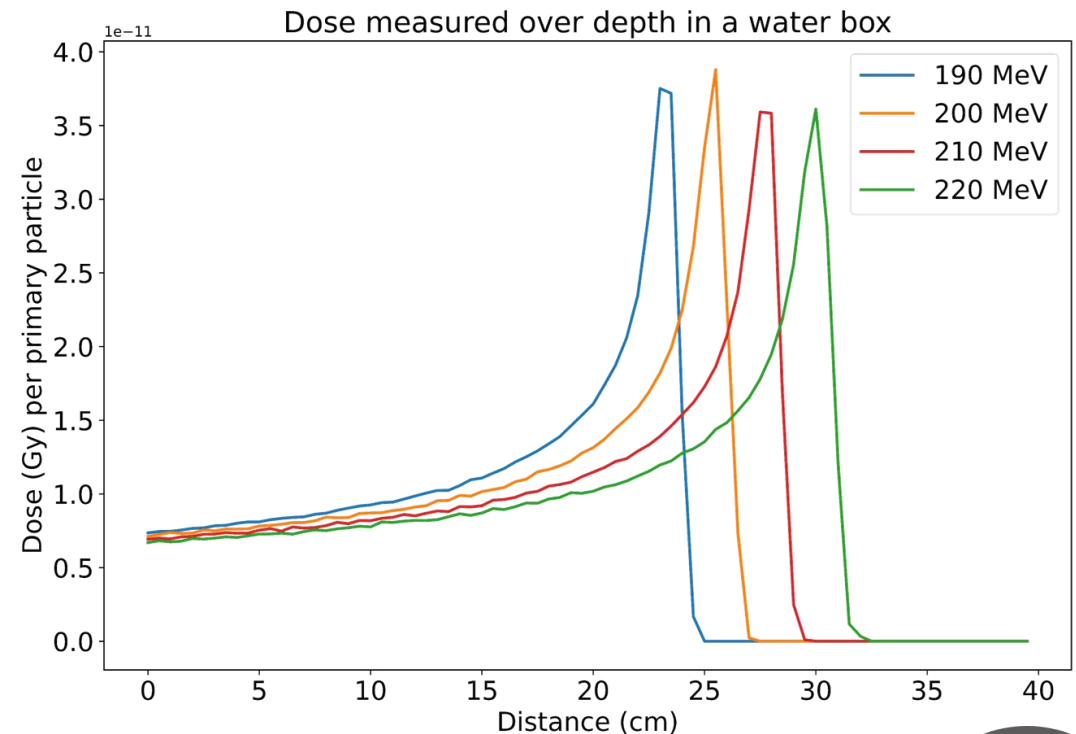
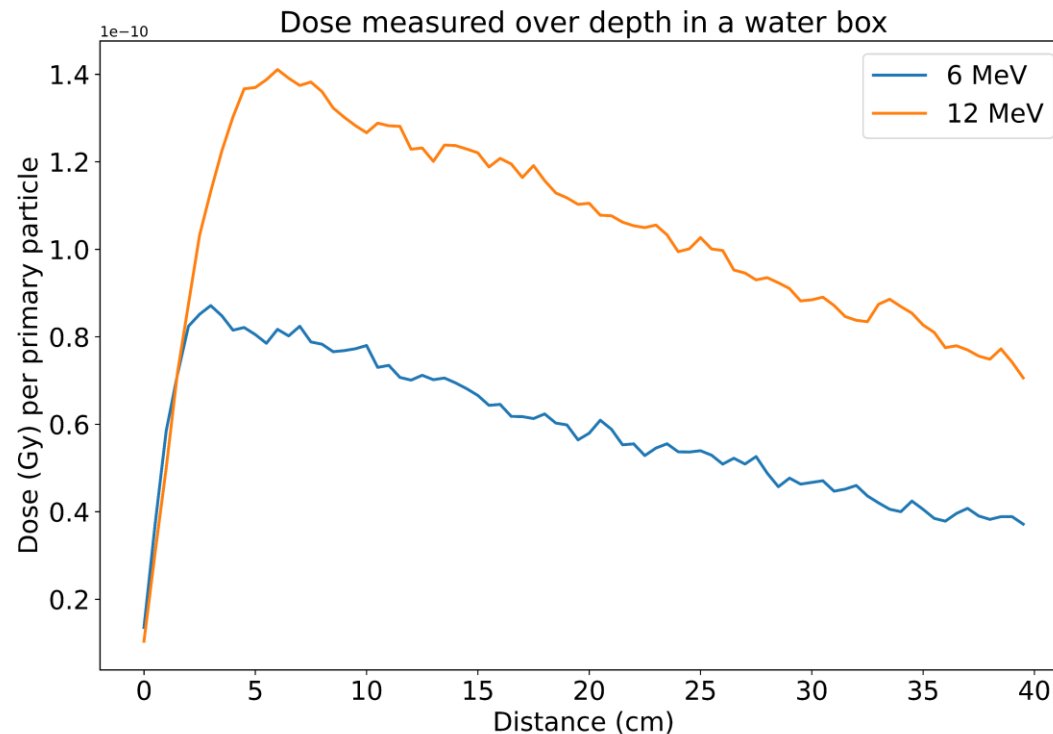
Hands-on session

Example 1 – Dose measured over depth in a water box

Example 2 – Radial Dose: Deposited dose as a function of the distance from the AuNP surface.

Example 1

Dose measured over depth in a water box



Example 1

Dose measured over depth in a water box

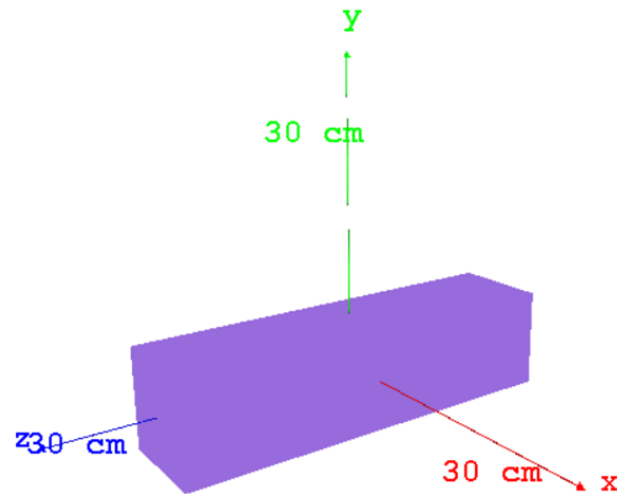
- Geometry: Water Box (10*10*40 cm³)
- Source:
 - The source beam direction was chosen to irradiate the box along the z-axis. Particle tracks were originated from a gaussian, and elliptical plane placed at the box begin.
 - Protons: 190, 200, 210 and 220 MeV; 100 histories
 - Gammas: 6 and 12 MeV; 50000 histories
- Physics: g4-livermore
 - Cut for gammas and electrons: 5 μ m
 - Fluorescence, Auger, Auger Cascade, Deexcitation Ignore Cut and PIXE activated.
- Scorer: DoseToMedium
 - Output file name: Dose_###MeV
 - You must indicate how many Zbins do you want
- Results analysis:
 - Example1_Plots.py: Example1_gammas.png and Example1_protons.png

Example 1

Dose measured over depth in a water box

- **Geometry:** Water Box

```
# Water Box with 10*10*40 cm3
s:Ge/MyBox/Type      = "TsBox"
s:Ge/MyBox/Material   = "G4_WATER"
s:Ge/MyBox/Parent    = "World"
d:Ge/MyBox/HLX       = 5 cm
d:Ge/MyBox/HLY       = 5 cm
d:Ge/MyBox/HLZ       = 20 cm
d:Ge/MyBox/TransX    = 0 m
d:Ge/MyBox/TransY    = 0 m
d:Ge/MyBox/TransZ    = 0 m
d:Ge/MyBox/RotY      = 0 deg
d:Ge/MyBox/RotZ      = 0 deg
s:Ge/MyBox/Color     = "skyblue"
s:Ge/MyBox/DrawingStyle = "solid"
```

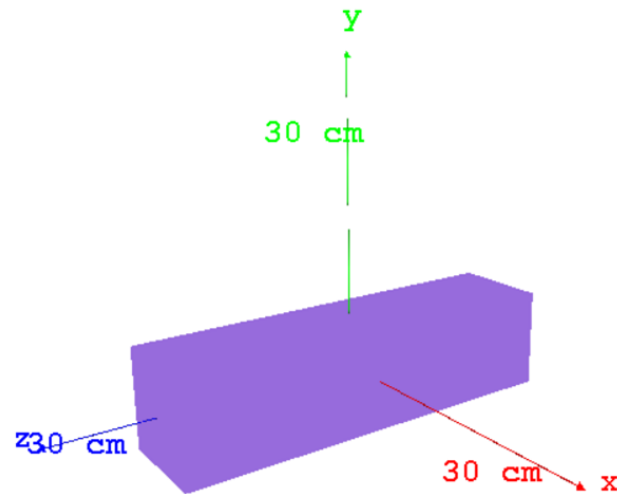


Example 1

Dose measured over depth in a water box

- **Geometry:** Water Box

```
# Water Box with 10*10*40 cm3
s:Ge/MyBox/Type      = "TsBox"
s:Ge/MyBox/Material   = "G4_WATER"
s:Ge/MyBox/Parent    = "World"
d:Ge/MyBox/HLX       = 5 cm
d:Ge/MyBox/HLY       = 5 cm
d:Ge/MyBox/HLZ       = 20 cm
d:Ge/MyBox/TransX    = 0 m
d:Ge/MyBox/TransY    = 0 m
d:Ge/MyBox/TransZ    = 0 m
d:Ge/MyBox/RotY      = 0 deg
d:Ge/MyBox/RotZ      = 0 deg
s:Ge/MyBox/Color     = "skyblue"
s:Ge/MyBox/DrawingStyle = "solid"
```



- **Physics**

- Cut for gammas and electrons: 5 μm
- Fluorescence, Auger, Auger Cascade, Deexcitation Ignore Cut and PIXE activated.

```
s:Ph/ListName          = "MyPhysics"
sv:Ph/MyPhysics/Modules = 1 "g4em-livermore"
s:Ph/MyPhysics/Type     = "Geant4_Modular"
d:Ph/MyPhysics/SetProductionCutLowerEdge = 100 eV
d:Ph/MyPhysics/CutForGamma      = 5 um
d:Ph/MyPhysics/CutForElectron   = 5 um
b:Ph/MyPhysics/Fluorescence     = "True"
b:Ph/MyPhysics/Auger            = "True"
b:Ph/MyPhysics/AugerCascade     = "True"
b:Ph/MyPhysics/DeexcitationIgnoreCut = "True"
b:Ph/MyPhysics/PIXE             = "True"
```

Example 1

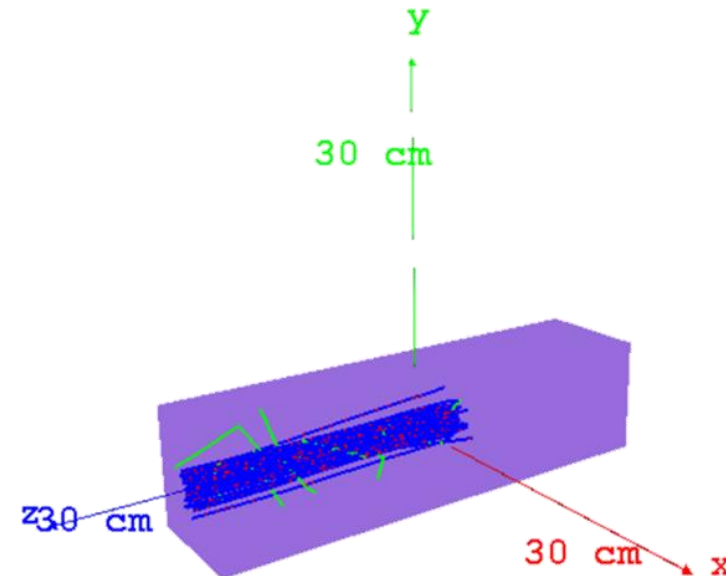
Dose measured over depth in a water box

- **Source:**

- The source beam direction was chosen to irradiate the box along the z-axis. Particle tracks were originated from a gaussian, and elliptical plane placed at the box begin.
- Protons: 190, 200, 210 and 220 MeV; 100 histories
- Gammas: 6 and 12 MeV; 50000 histories

```
s:So/MySource/Type = "Beam"  
s:So/MySource/Component = "BeamPosition"  
s:So/MySource/BeamParticle = "proton"  
d:So/MySource/BeamEnergy = 190 MeV  
u:So/MySource/BeamEnergySpread = 0.757504  
s:So/MySource/BeamPositionDistribution = "Gaussian"  
s:So/MySource/BeamPositionCutoffShape = "Ellipse"  
d:So/MySource/BeamPositionCutoffX = 10. cm  
d:So/MySource/BeamPositionCutoffY = 10. cm  
d:So/MySource/BeamPositionSpreadX = 0.65 cm  
d:So/MySource/BeamPositionSpreadY = 0.65 cm  
s:So/MySource/BeamAngularDistribution = "None"  
i:So/MySource/NumberOfHistoriesInRun = 100
```

```
s:Ge/BeamPosition/Parent = "World"  
s:Ge/BeamPosition/Type = "Group"  
d:Ge/BeamPosition/TransX = 0. m  
d:Ge/BeamPosition/TransY = 0. m  
d:Ge/BeamPosition/TransZ = Ge/MyBox/HLZ cm  
d:Ge/BeamPosition/RotX = 180. deg  
d:Ge/BeamPosition/RotY = 0. deg  
d:Ge/BeamPosition/RotZ = 0. deg
```

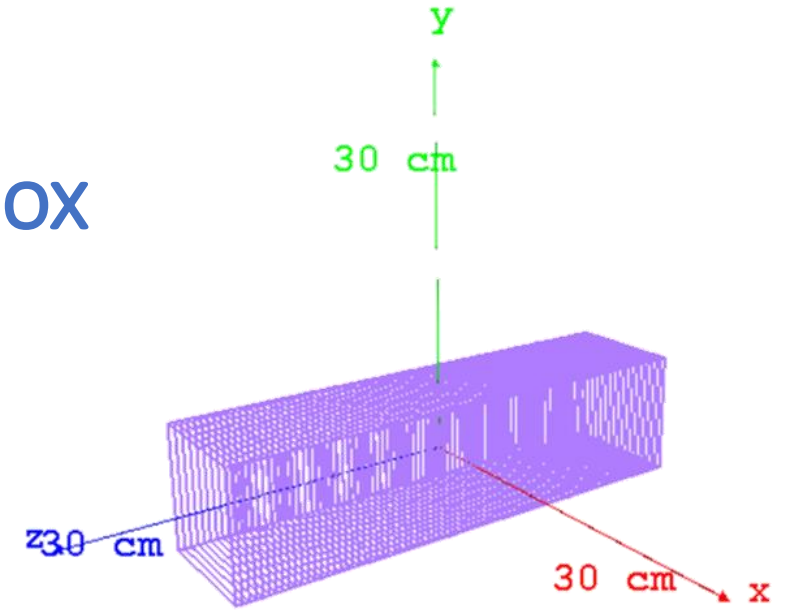


Example 1

Dose measured over depth in a water box

- **Scorer:** DoseToMedium
 - Output file name: Dose_###MeV
 - You must indicate how many Zbins do you want

```
s:Sc/DoseAtPhantom/Quantity = "DoseToMedium"  
s:Sc/DoseAtPhantom/Component = "MyBox"  
s:Sc/DoseAtPhantom/IfOutputFileAlreadyExists = "Overwrite"  
b:Sc/DoseAtPhantom/OutputToConsole = "False"  
i:Sc/DoseAtPhantom/ZBins = 80  
s:Sc/DoseAtPhantom/OutputFile = "Dose_190MeV"  
# Rotate Phantom so that the bin numbered 0 will be the  
# first bin hit.  
d:Ge/MyBox/RotX = 180. deg
```

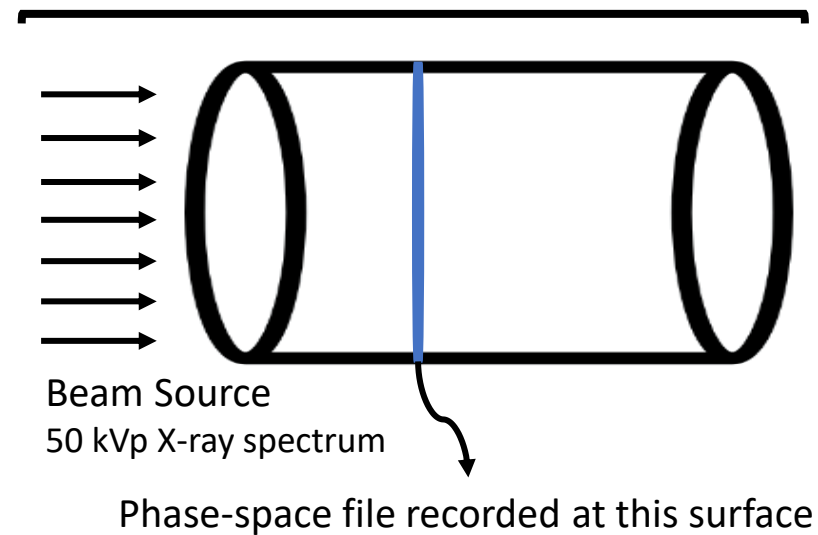


- **Results analysis:**
 - Example1_Plots.py: Example1_gammas.png and Example1_protons.png

Example 2

Radial Dose

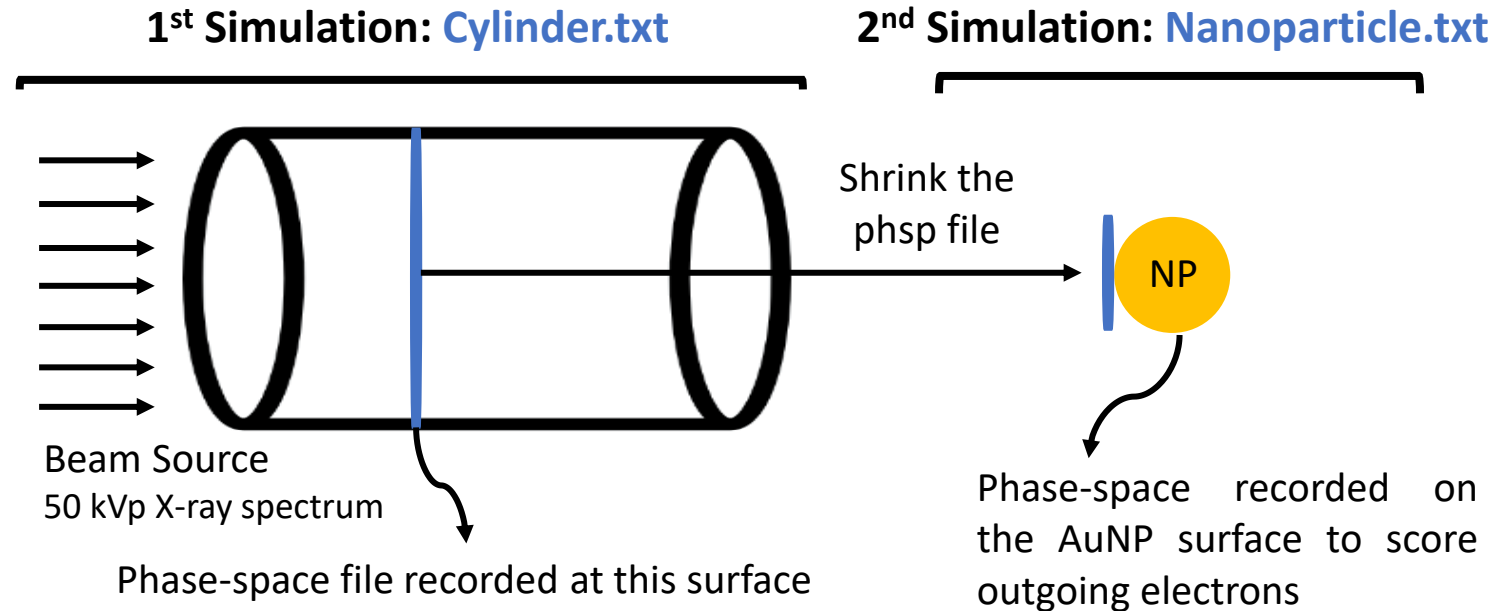
1st Simulation: [Cylinder.txt](#)



- **Physics:** g4-Livermore or g4-dna
 - Cut for gammas and electrons: 1 nm
 - Fluorescence, Auger, Auger Cascade, Deexcitation Ignore Cut and PIXE activated.

Example 2

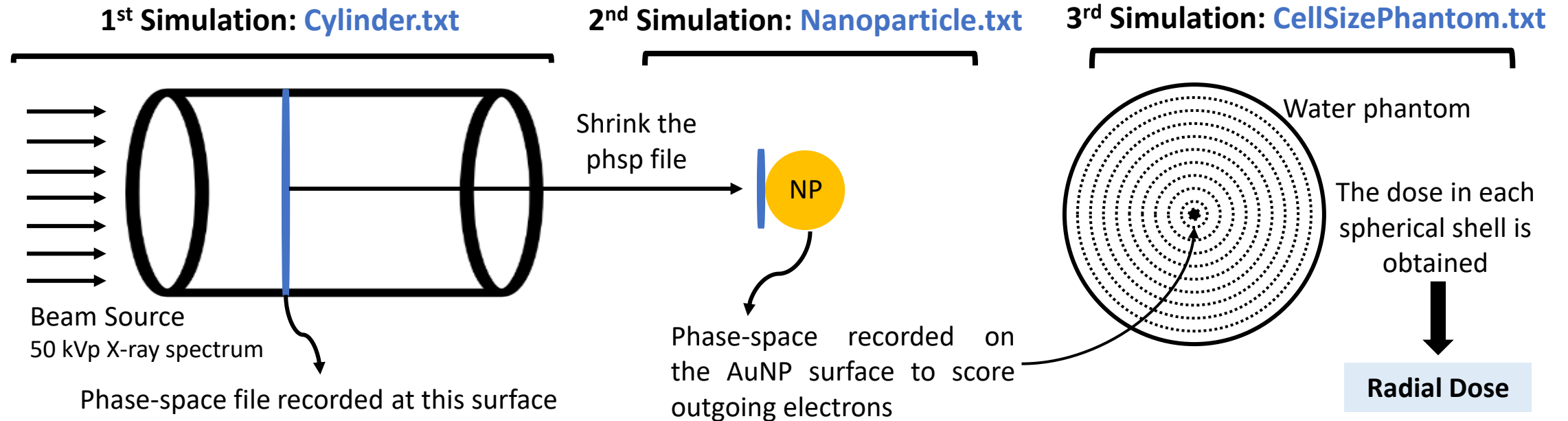
Radial Dose



- **Physics:** g4-livermore
 - Cut for gammas and electrons: 1 nm
 - Fluorescence, Auger, Auger Cascade, Deexcitation Ignore Cut and PIXE activated.

Example 2

Radial Dose



- **Physics:** g4-dna
 - Cut for gammas and electrons: 0.5 nm
 - Fluorescence, Auger, Auger Cascade, Deexcitation Ignore Cut and PIXE activated.
- **Scorer:** DoseToMedium