GATE training on medical imaging (PET, SPECT, CT), dosimetry and radiation therapy – Beginner level

Day2
Session 8 – SPECT Imaging PART I

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2020.02.13.Thu.

Tohoku University, Cyclotron and Radioisotope Center (CYRIC)
(G11) Lecture room 2F

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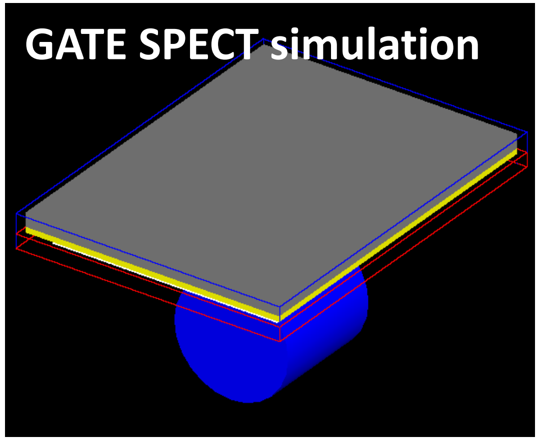
Outline



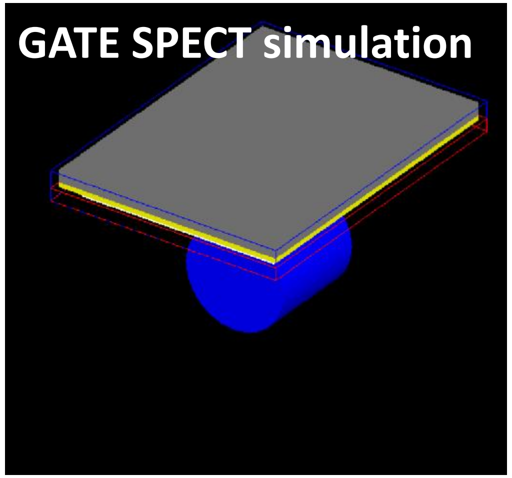
Modeling a clinical SPECT system

- ✓ SIEMENS Symbia T2 SPECT

GATE simulation steps

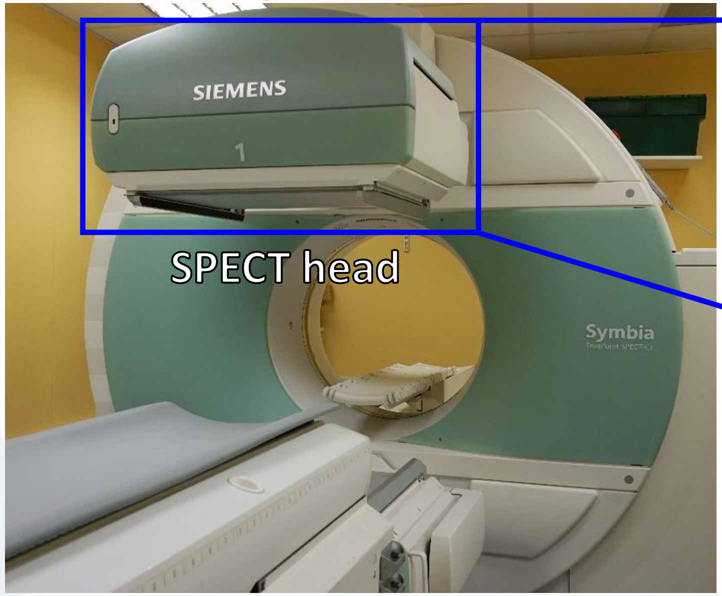
- ✓ STEP 1> Select the **system type** in accordance with your imaging modality
- ✓ STEP 2> **Define the detector geometry (Most important and difficult)**
- ✓ STEP 3> Define the **phantom** and **source** geometry
- ✓ STEP 4> Physics list setting
- ✓ STEP 5> Initialization
- ✓ STEP 6> **Digitizer** setting
- ✓ STEP 7> Choose your **output format**
- ✓ STEP 8> **GATE run!**

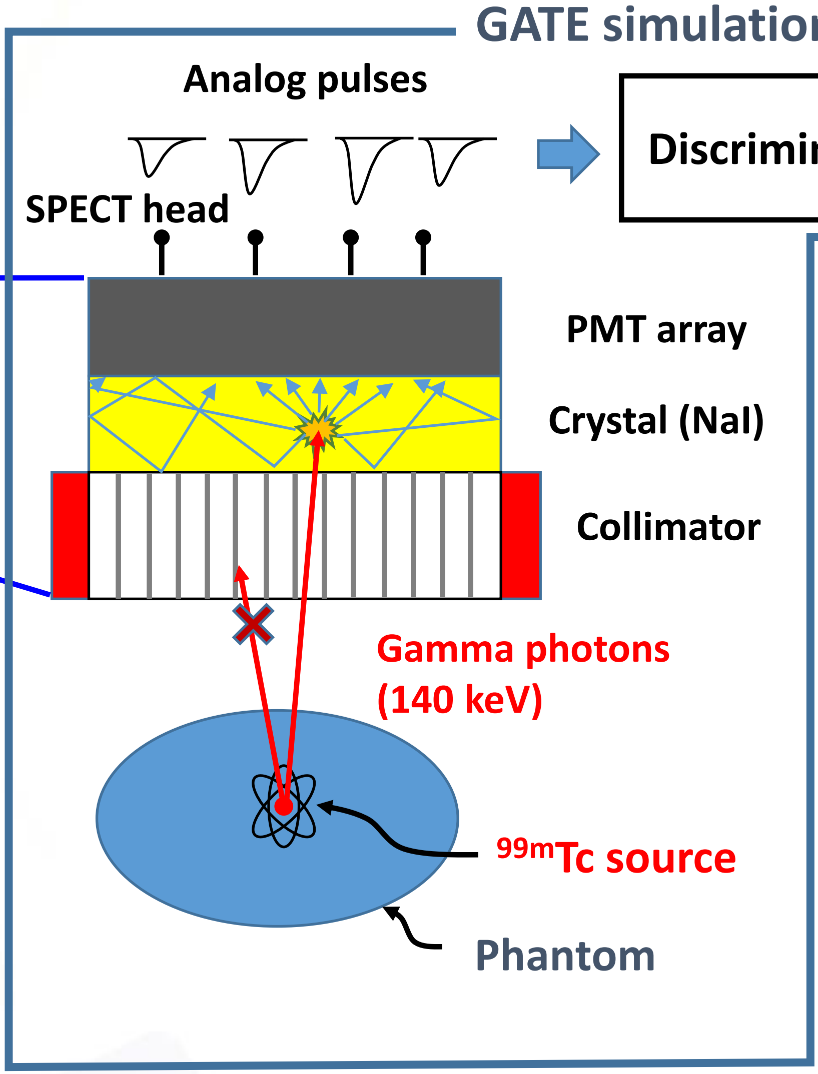
Goal: Modeling of a clinical SPECT system

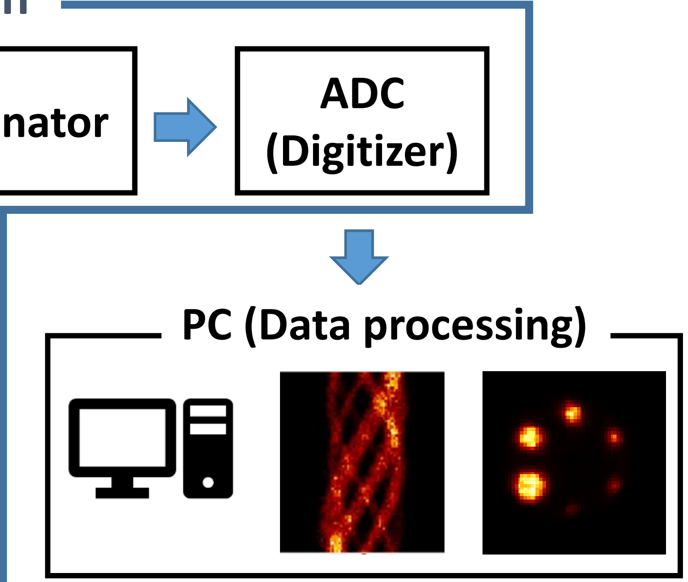


SPECT (Single Photon Emission Computed Tomography)

SIEMENS Symbia T2 SPECT/CT



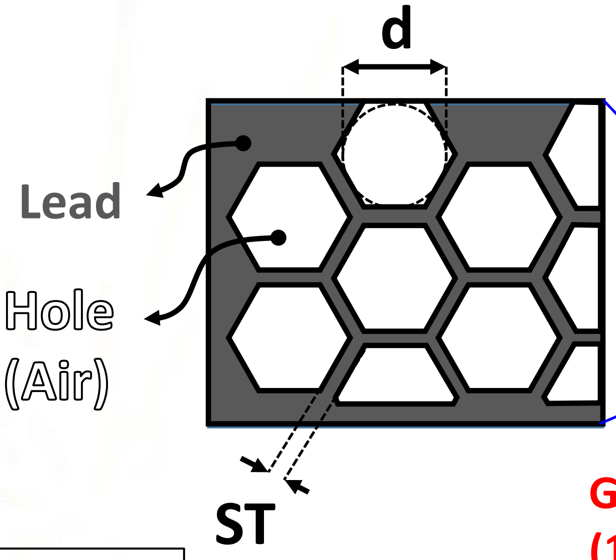


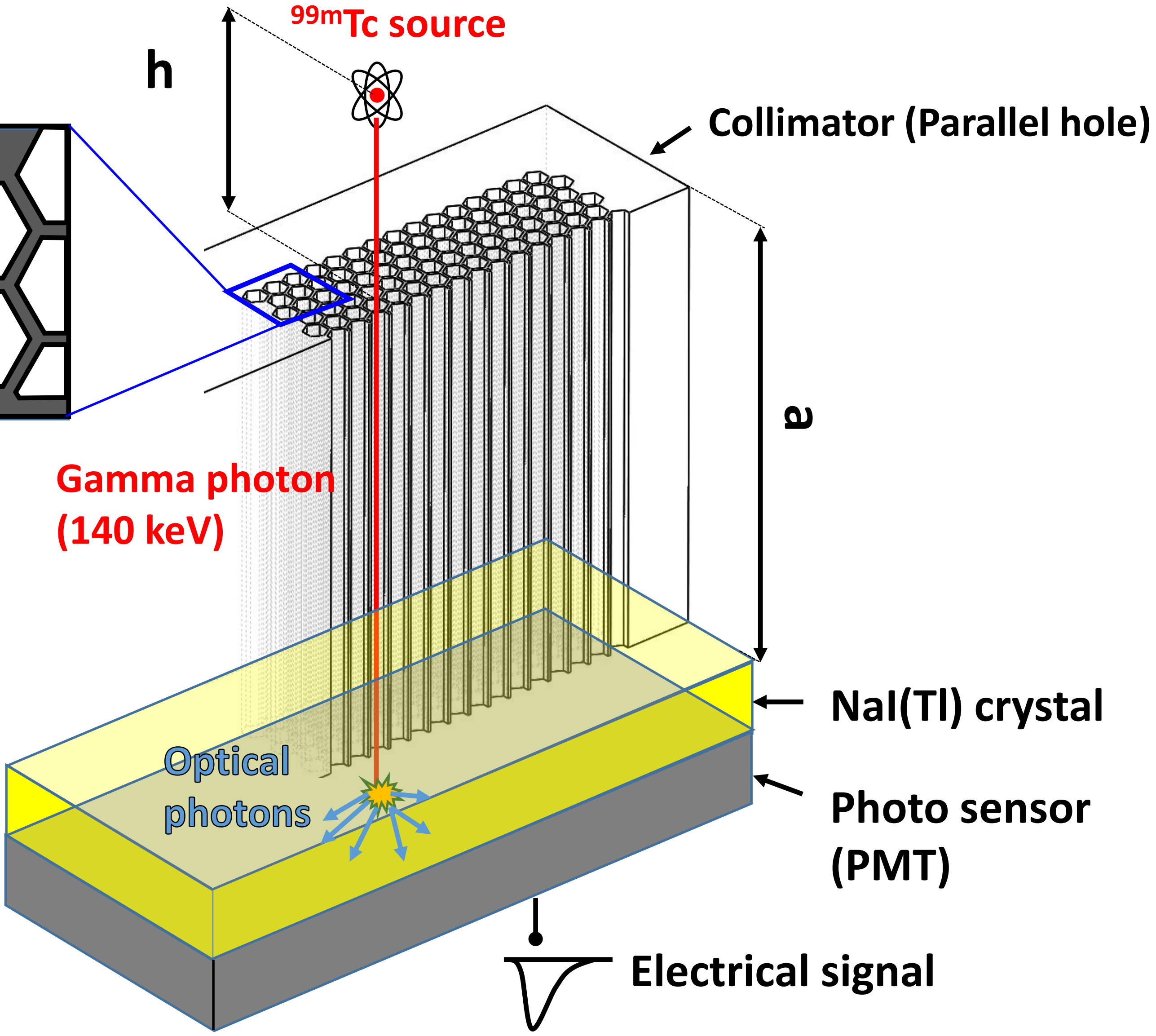


What you need to set in GATE

- Collimator
- Scintillator(=crystal)
- Detector response
- Phantom
- Source

Collimator





Higher↑ is better

$$Sensitivity = \frac{\sqrt{3}}{8}\frac{d^2}{a^2}\frac{d^2}{(d+ST)^2}$$

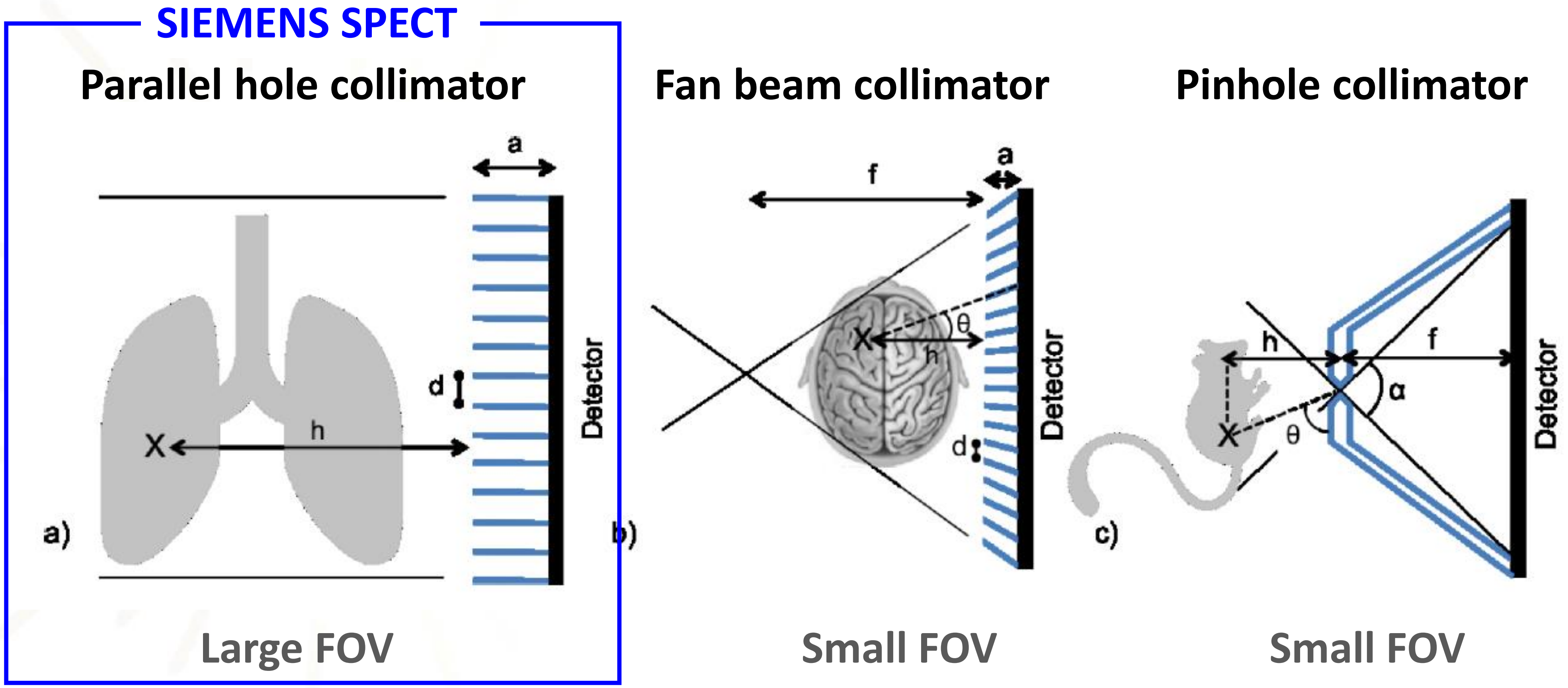
length (a), diameter (d), Septal thickness (ST)

$$Resolution = d\frac{a+h}{a}$$

h: Distance from the source to collimator

Smaller ↓ is better

Collimator types

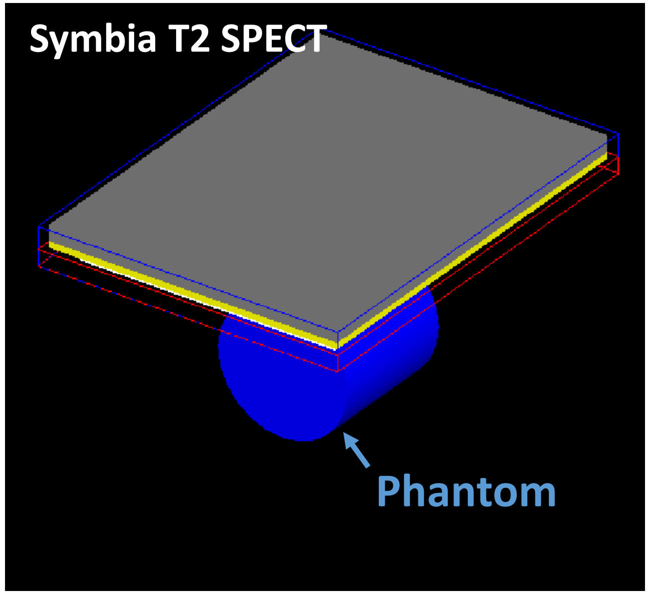


K V Audenhaege et al., 2015 Medical Physics

Clinical SPECT simulation (SPECThead)

SIEMENS Symbia T2 SPECT/CT

GATE SPECT simulation



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GATE projection output (*.sin)

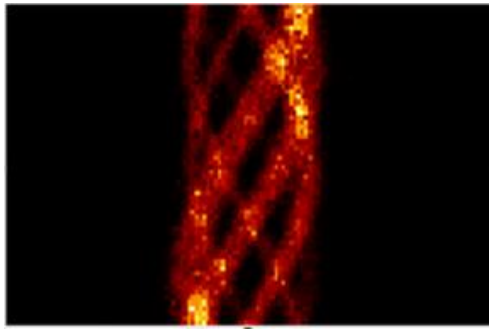
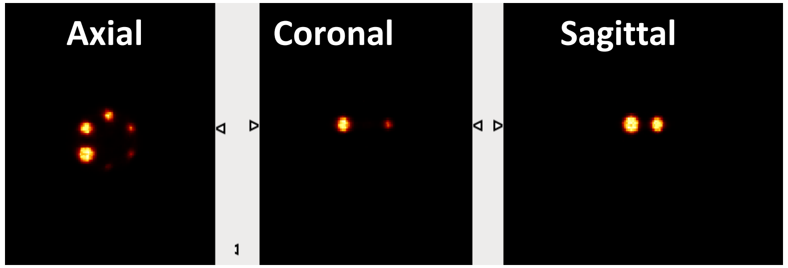


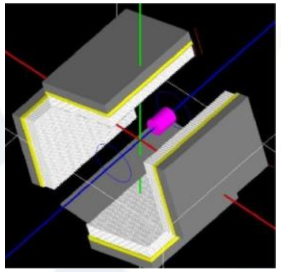
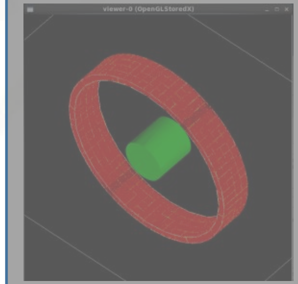
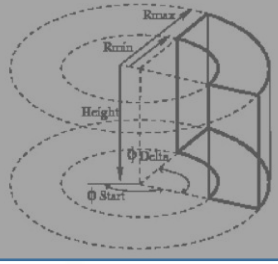
Image reconstruction using STIR*

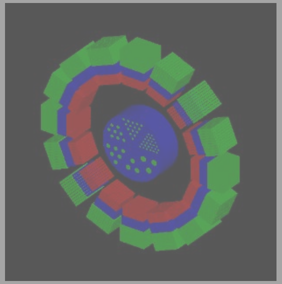
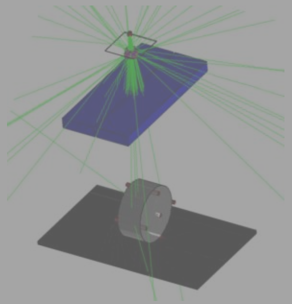
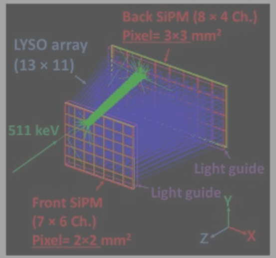


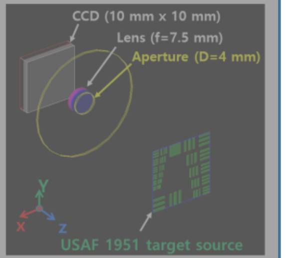
*STIR (Software for Tomographic Image Reconstruction)

Different types of systems

SPECThead	ECAT	CylindricalPET	PETscanner	CTscanner	Scanner	Optical System
SPECThead	ecat	cylindricalPET	PETscanner	CTscanner	scanner	OpticalSystem
crystal	block	rsector	level1	module	level1	crystal
pixel	crystal	module	level2	cluster	level2	pixel
		crystal	level3	pixel	level3	
		layer0	level4		level4	
		layer1	level5		level5	



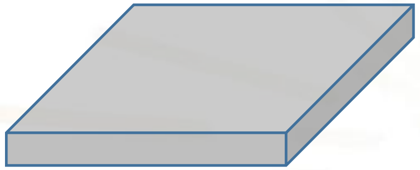
Predefined systems in GATE

Select the “**system**” in accordance with your imaging modality.

Modality	System	Possible Geometry	Attach Keyword Argument	Depth for readout	Available Outputs
Detector PET	scanner or PETscanner	geometry not fixed	"level1" "level2" "level3" "level4" "level5"	1 2 3 4 5	Basic output: ASCII or ROOT, coincidences only for PETscanner
CT	CTscanner	box box box	"module" "cluster_0...2" "pixel_0...2"	1 2 3	Raw Data, ASCII, ROOT
C-shape PET	CPET	cylinder cylinder box box box	"sector" "cassette" "module" "crystal" "layer[i], i=0,3"	1 2 3 4 5	Basic Output: ASCII, ROOT
Cylindrical PET	cylindricalPET	box box box box box	"rsector" "module" "submodule" "crystal" "layer[i], i=0,3"	1 2 3 4 5	Basic Output: ASCII, ROOT and Raw. Specific: LMF
SPECT	SPECThead	geometry not fixed	crystal pixel	1 2	Basic Output: ASCII, ROOT and Raw. Specific: PROJECTIONSET or INTEFILE, no coincidences
ECAT PET	ecat	box	block crystal	1 2	Basic Output: ASCII, ROOT and Raw. Specific: SINOGRAM or ECAT7
	ecatAccel	box	block crystal	1 2	Basic Output: ASCII, ROOT and Raw. Specific: SINOGRAM or ECAT7
	OPET	box box box box wedge	rsector module submode crystal layer	1 2 3 4 5	Basic Output: ASCII, ROOT and Raw. Specific: LMF
Optical imaging	OpticalSystem	geometry not fixed	crystal pixel	1 2	Basic Output: ROOT and Raw. Specific: PROJECTION SET

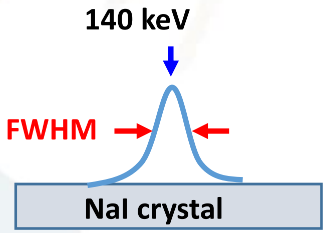
Symbia T2 SPECT specifications (crystal)

Crystal dimensions (NaI, 59.1×44.5 cm^2)



Detector Shielding

Intrinsic spatial resolution=3.8 mm



Detector Dimensions	Symbia T Series
FOV	53.3x38.7 cm (21x15.25 in)
Diagonal FOV	65.9 cm (25.9 in)

Crystal	Symbia T Series
Size	59.1x44.5 cm (23.25x17.5 in)
Diagonal	73.9 cm (29.1 in)
Thickness	9.5 mm (3/8 in) or 15.9 mm (5/8 in)

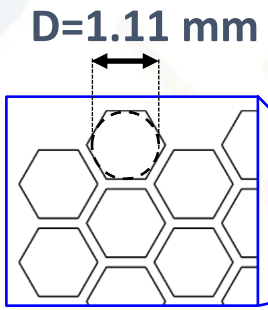
Photomultiplier Tubes	Symbia T Series
Total Number	59
Diameter	53-7.6 cm (3 in) and 6-5.1 cm (2.4-2 in)
Type	Bialkali high-efficiency box-type dynodes
Array	Hexagonal

Detector Shielding	Symbia T Series
Back	9.5 mm (0.375 in)
Sides	12.7 mm (0.5 in)

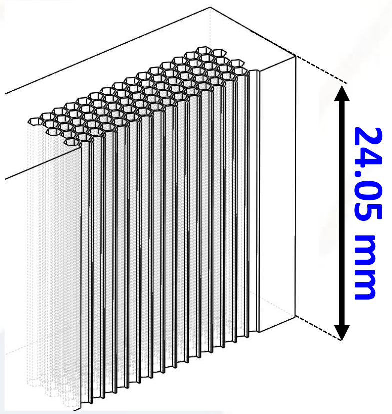
Detector***	3/8"	5/8"
Intrinsic Spatial Resolution		
FWHM in CFOV	≤3.8 mm	≤4.5 mm
FWHM in UFOV	≤3.9 mm	≤4.6 mm
FWTM in CFOV	≤7.5 mm	≤8.7 mm
FWTM in UFOV	≤7.7 mm	≤8.9 mm
Intrinsic Energy Resolution		
FWHM in CFOV	≤9.9%	≤9.9%

Symbia T2 SPECT specifications (Collimator)

LEHR (Low Energy High Resolution)



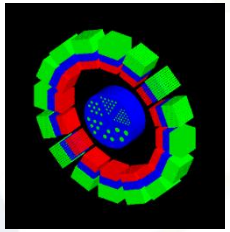
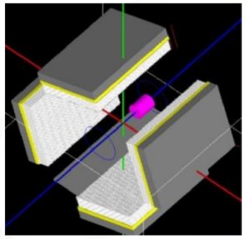
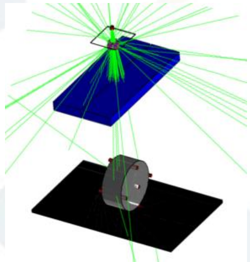
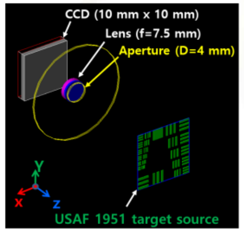
LEHR Collimator
- **Length = 24.05 mm**
- **Septa = 0.16 mm**
- **Hole = 1.11 mm**



Collimators	LEHR	LEAP	LEUHR	LEFB	ME	HE	SMART-ZOOM
	Low Energy High Resolution	Low Energy All Purpose	Low Energy Ultra High Resolution	Low Energy Fan Beam	Medium Energy	High Energy	IQ•SPECT
Isotope	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{67}Ga	^{131}I	^{99m}Tc
Hole Shape	Hex	Hex	Hex	Hex	Hex	Hex	Hex
Number of Holes (x1000)	148	90	146	64	14	8	48
Hole Length	24.05 mm	24.05 mm	35.8 mm	35 mm	40.64 mm	59.7 mm	40.25 mm
Septal Thickness	0.16 mm	0.2 mm	0.13 mm	0.16 mm	1.14 mm	2 mm	0.2-0.4
Hole Diameter Across the Flats	1.11 mm	1.45 mm	1.16 mm	1.53 mm	2.94 mm	4 mm	1.9 mm
Sensitivity at 10 cm*	202 cpm/ µCi	330 cpm/ µCi	100 cpm/ µCi	280 cpm/ µCi	275 cpm/ µCi	135 cpm/ µCi	285 cpm/ µCi**
							810 cpm/µCi at 28 cm**
Geometric Resolution at 10 cm	6.4 mm	8.3 mm	4.6 mm	6.3 mm	10.8 mm	13.2 mm	6.95 mm
System Resolution at 10 cm*	7.5 mm	9.4 mm	6.0 mm	7.3 mm	12.5 mm	13.4 mm	7.4 mm***
Septal Penetration	1.5%	1.9%	0.8%	1.0%	1.2%	3.5%	N/A

STEP 1> Select the system type

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on

STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

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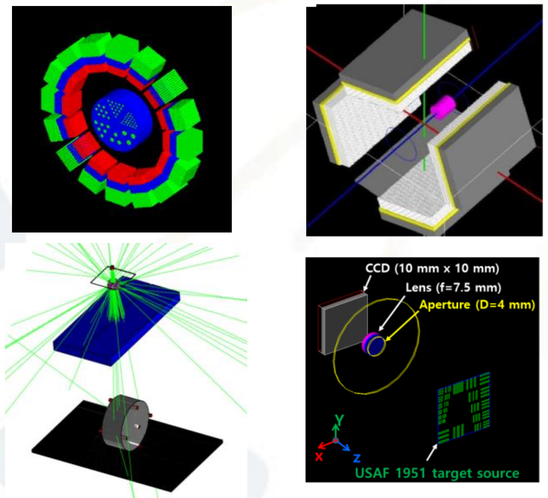

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Defining the World

```
# ==================================
# V I S U A L I S A T I O N
# ==================================
/vis/disable
#/control/execute ./macro/Vis.mac

# ==================================
# GATE Material read
# ==================================
/gate/geometry/setMaterialDatabase GateMaterials.db

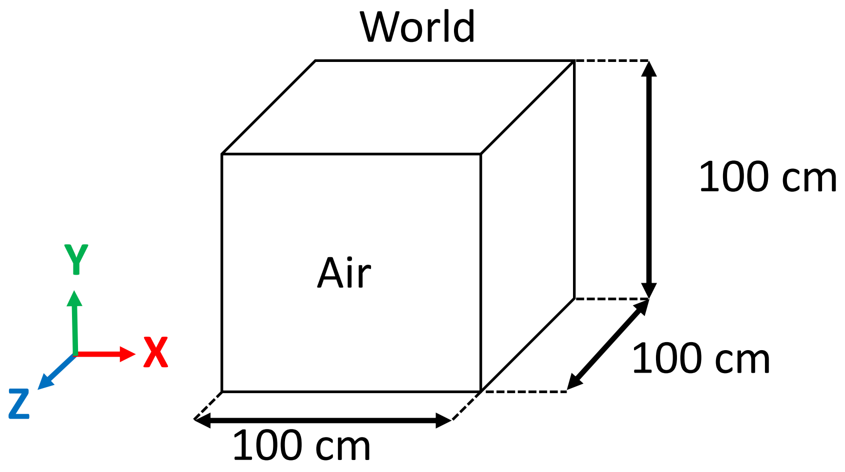
# ==================================
# World
# ==================================
# Define the world dimensions
/gate/world/geometry/setXLength 100 cm
/gate/world/geometry/setYLength 100 cm
/gate/world/geometry/setZLength 100 cm
/gate/world/setMaterial Air
/gate/world/vis/setVisible 0
```

Read the GateMaterials.db

```
Air: d=1.29 mg/cm3 ; n=4 ; state=gas
        +el: name=Nitrogen;    f=0.755268
        +el: name=Oxygen;      f=0.231781
        +el: name=Argon;       f=0.012827
        +el: name=Carbon;      f=0.000124

Lead: d=11.4 g/cm3 ; n=1 ; state=solid
        +el: name=auto ; n=1

NaI: d=3.67 g/cm3; n=2;  state=solid
        +el: name=Sodium ; n=1
        +el: name=Iodine ; n=1
```

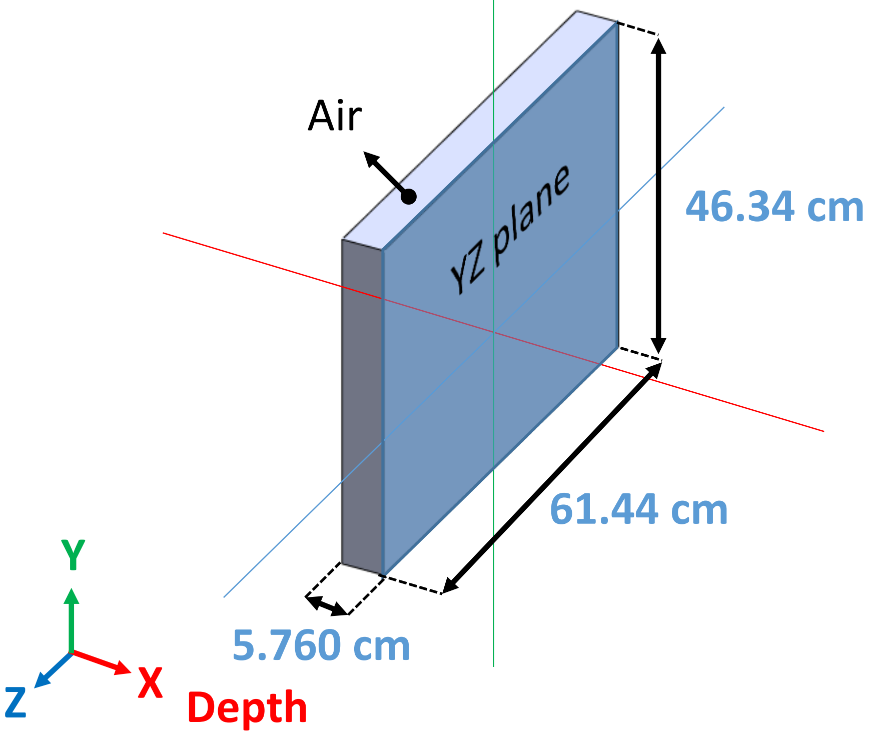


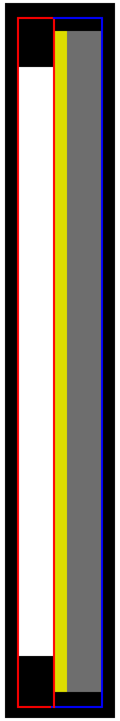
Defining a SPECT system (SPECThead)

```
# ==========================================================
# Scanner Head
# Create a new box representing the main head-volume
# SPECThead is the name of the predefined SPECT system
# Create the SPECT system, which will yield
# an Interfile output of projection data
# ==========================================================

# ==========================================================
# SPECThead
# ==========================================================
/gate/world/daughters/name SPECThead
/gate/world/daughters/insert box
/gate/SPECThead/geometry/setXLength  5.760 cm
/gate/SPECThead/geometry/setYLength 46.34 cm
/gate/SPECThead/geometry/setZLength 61.44 cm
/gate/SPECThead/setMaterial Air
/gate/SPECThead/vis/forceWireframe
#/gate/SPECThead/vis/forceSolid
```

NOTE! SPECThead is in YZ plane.
Depth orientation is X-direction.





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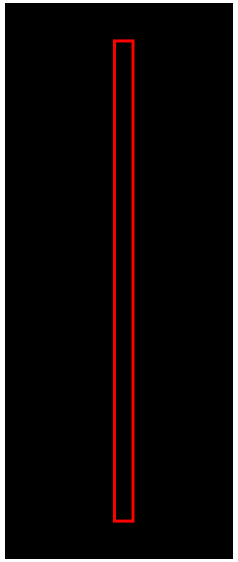
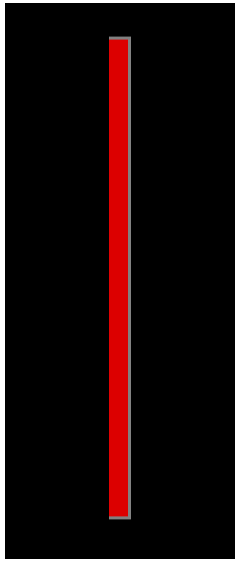
/gate/SPECThead/geometry/setZLength 61.44 cm
/gate/SPECThead/setMaterial Air
/gate/SPECThead/vis/forceWireframe
#/gate/SPECThead/vis/forceSolid
```

Visualization option

1.forceWireframe



2.forceSolid



You can see inside the volume

STEP 2> Define the detector geometry

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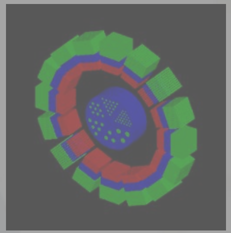
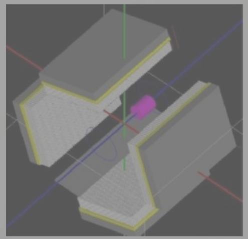
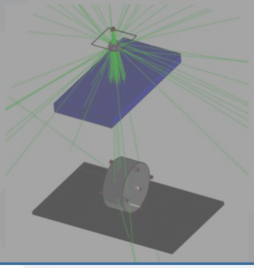
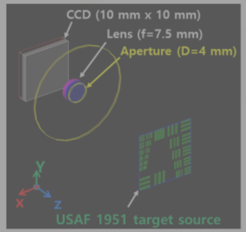
- ✓ and so on

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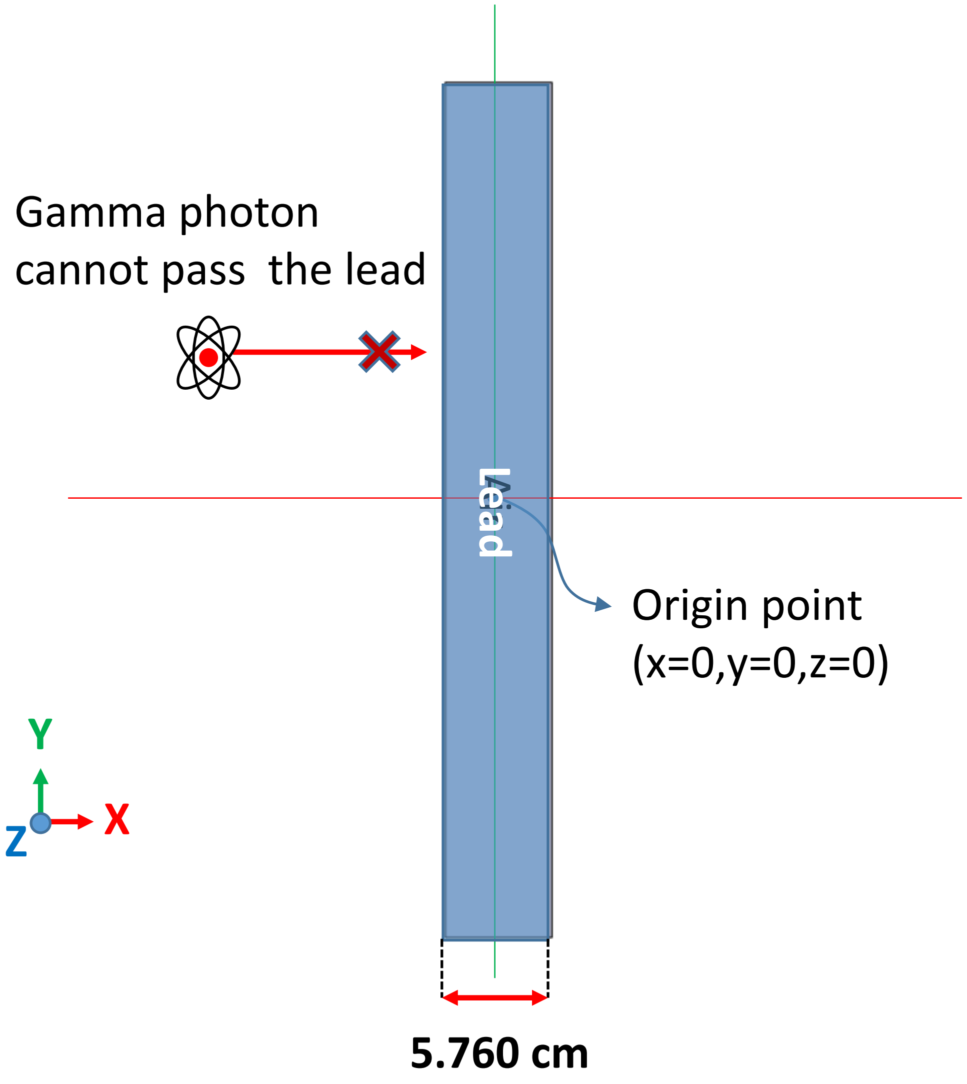
Defining SPECT shielding

```
# ==========================================================
# SPECThead -> shielding(Lead)
# ==========================================================
# Create the shielding volume
/gate/SPECThead/daughters/name shielding
/gate/SPECThead/daughters/insert box
/gate/shielding/geometry/setXLength  5.760 cm
/gate/shielding/geometry/setYLength 46.34 cm
/gate/shielding/geometry/setZLength 61.44 cm
/gate/shielding/placement/setTranslation  0. 0. 0. cm
/gate/shielding/setMaterial Lead
/gate/shielding/vis/setColor blue
/gate/shielding/vis/forceWireframe
```

Identical dimensions with the SPECThead

GateMaterials.db

```
Lead: d=11.4 g/cm3 ; n=1 ; state=solid
        +el: name=auto ; n=1
```



Defining SPECT collimator

```
# =============================================================
# SPECThead -> collimator(Lead)
# =============================================================
# Create a collimator volume
/gate/SPECThead/daughters/name collimator
/gate/SPECThead/daughters/insert box
/gate/collimator/geometry/setXLength  2.405 cm
/gate/collimator/geometry/setYLength 46.34 cm
/gate/collimator/geometry/setZLength 61.44 cm
/gate/collimator/placement/setTranslation  -1.6775  0.  0. cm
/gate/collimator/setMaterial Lead
/gate/collimator/vis/setColor red
/gate/collimator/vis/forceWireframe
```

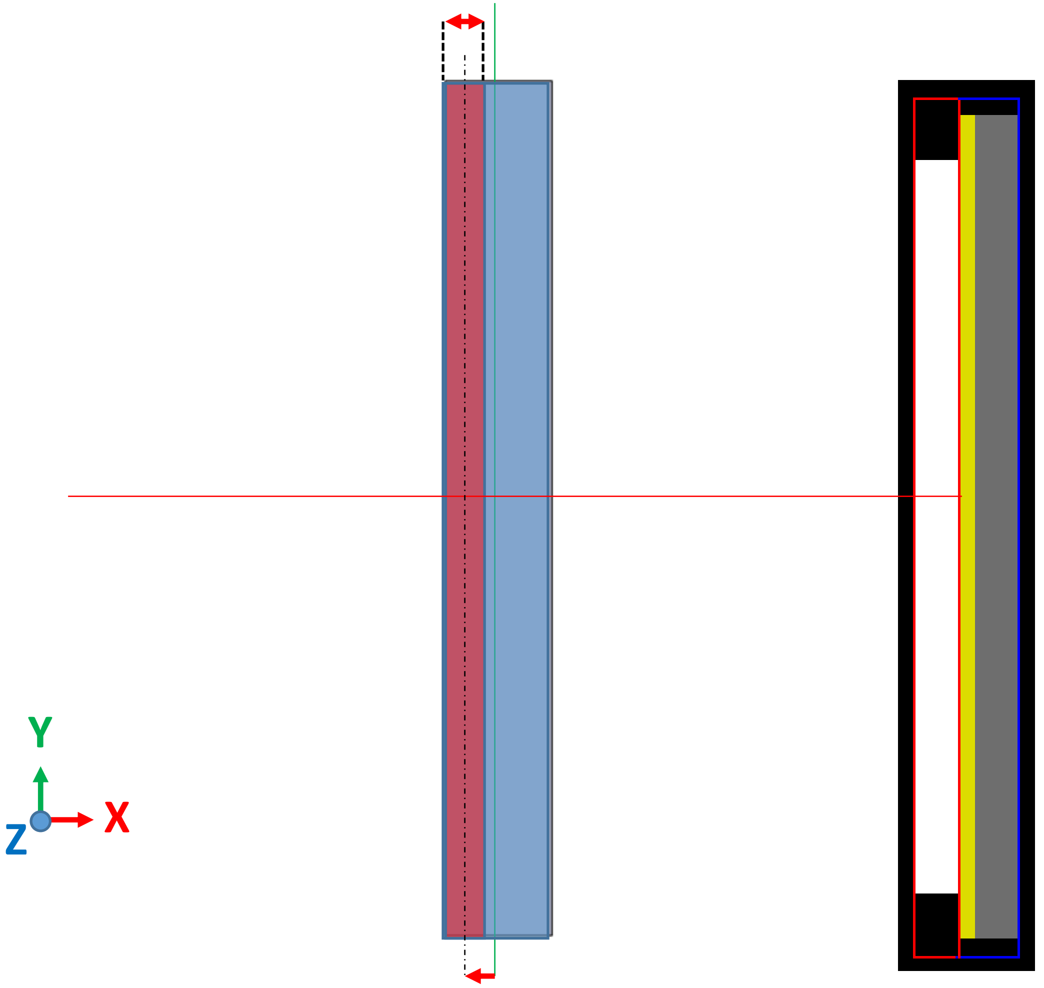
Collimator dimensions (setXLength, setYLength, setZLength)

GateMaterials.db

```
Lead: d=11.4 g/cm3 ; n=1 ; state=solid
        +el: name=auto ; n=1
```

Collimator (Lead)

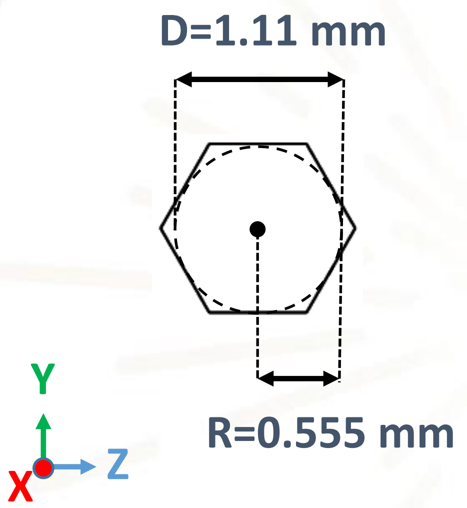
2.405 cm



Translate the collimator **-1.6775 cm** in X-dir.

How to calculate the collimator pitch

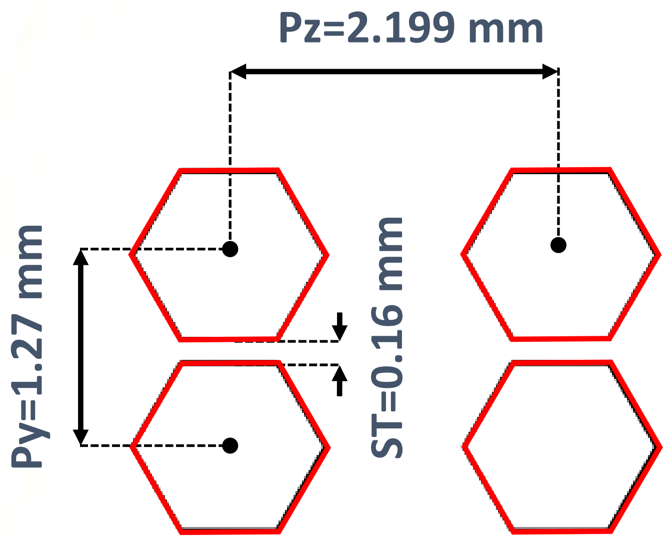
Create a single hole



D : Hole inner diameter

ST : Septal Thickness

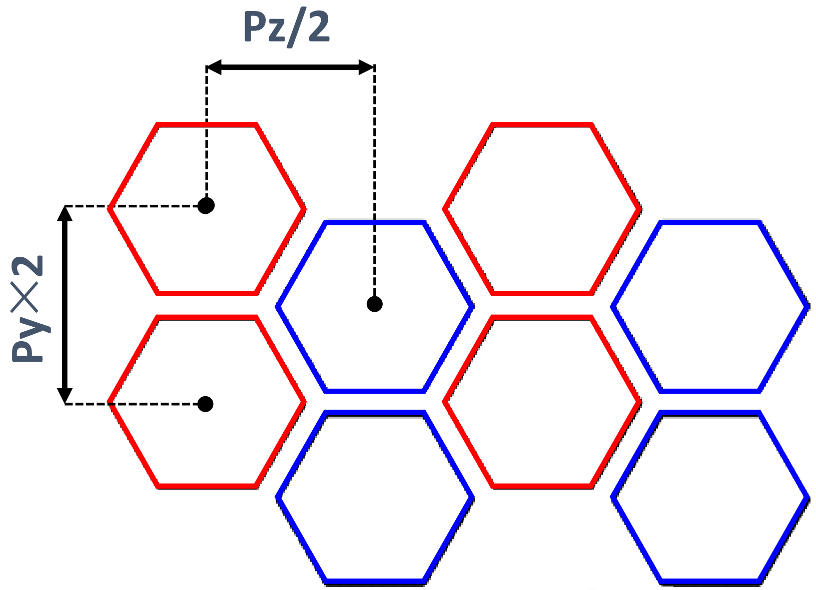
Repeater: cubicArray

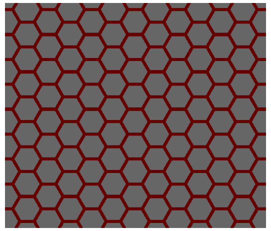


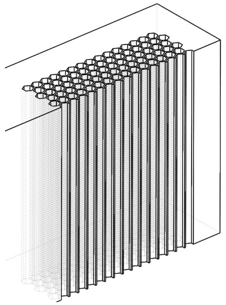
$$P_y = D + ST\ [mm]$$

$$P_z = 2\sqrt{\left((D+ST)^2 - \left(\frac{D+ST}{2}\right)^2\right)}\ [mm]$$

Repeater: linear



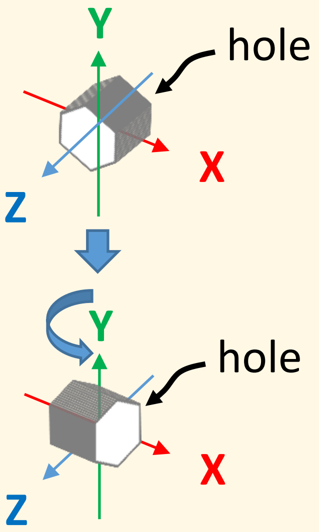




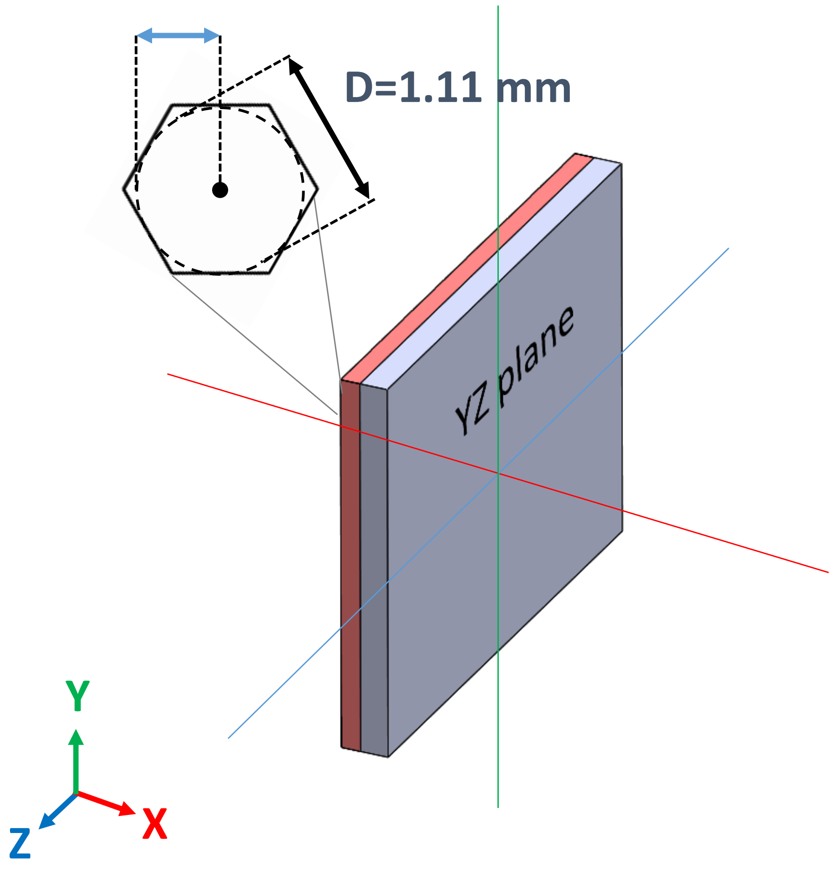
Defining SPECT collimator (hole)

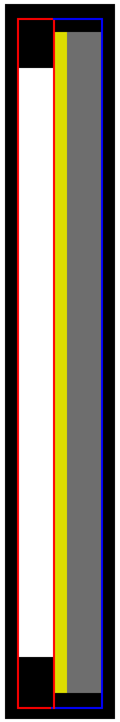
```
# ========================================================
# SPECThead -> collimator -> hole
# Insert the first hole of air in the collimator
# Symbia LEHR (D=1.11 mm, l=24.05 mm, Septa = 0.16 mm)
# ========================================================
/gate/collimator/daughters/name hole
/gate/collimator/daughters/insert hexagone
/gate/hole/geometry/setHeight 24.05 mm
/gate/hole/geometry/setRadius 0.555 mm
/gate/hole/setMaterial Air

# Rotate the hole in YZ plane
/gate/hole/placement/setRotationAxis 0 1 0
/gate/hole/placement/setRotationAngle 90 deg
```



You have to rotate the hole in YZ plane!

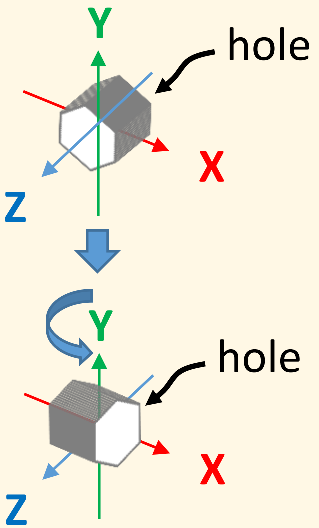




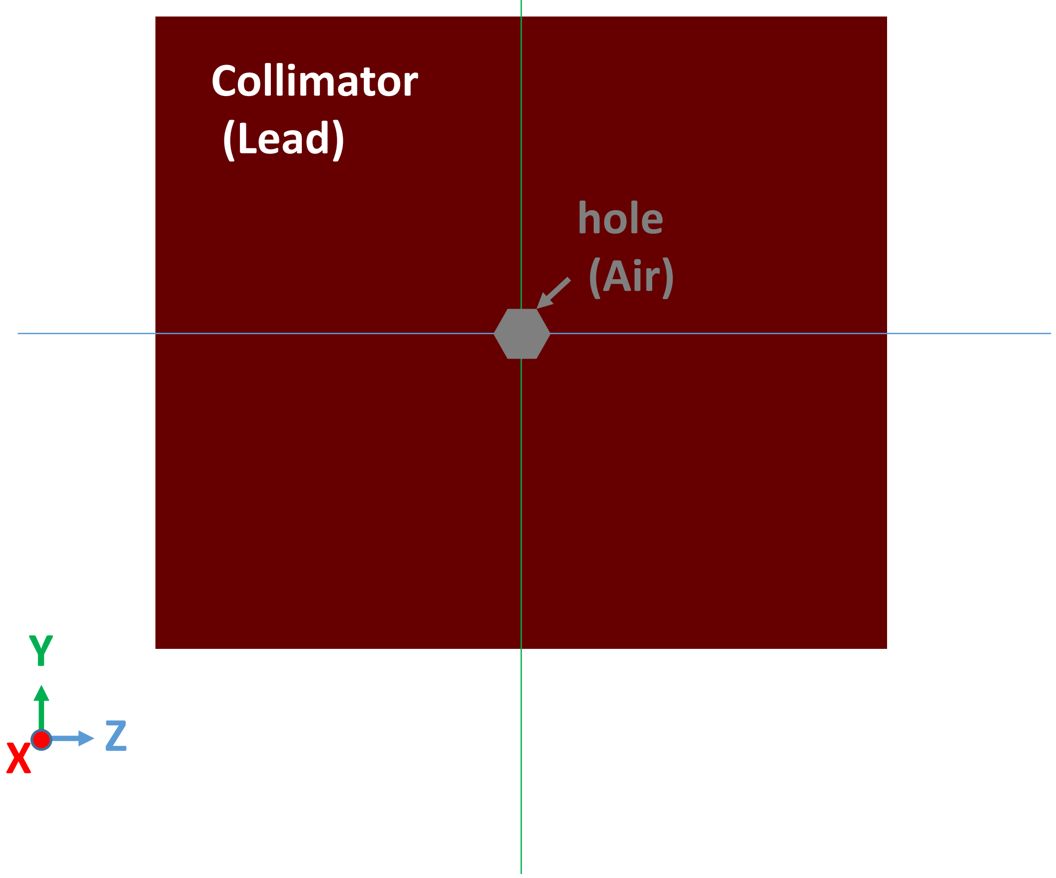
Defining SPECT collimator (hole)

```
# ==========================================================
# SPECThead -> collimator -> hole
# Insert the first hole of air in the collimator
# Symbia LEHR (D=1.11 mm, l=24.05 mm, Septa = 0.16 mm)
# ==========================================================
/gate/collimator/daughters/name hole
/gate/collimator/daughters/insert hexagone
/gate/hole/geometry/setHeight 24.05 mm
/gate/hole/geometry/setRadius 0.555 mm
/gate/hole/setMaterial Air

# Rotate the hole in YZ plane
/gate/hole/placement/setRotationAxis 0 1 0
/gate/hole/placement/setRotationAngle 90 deg
```



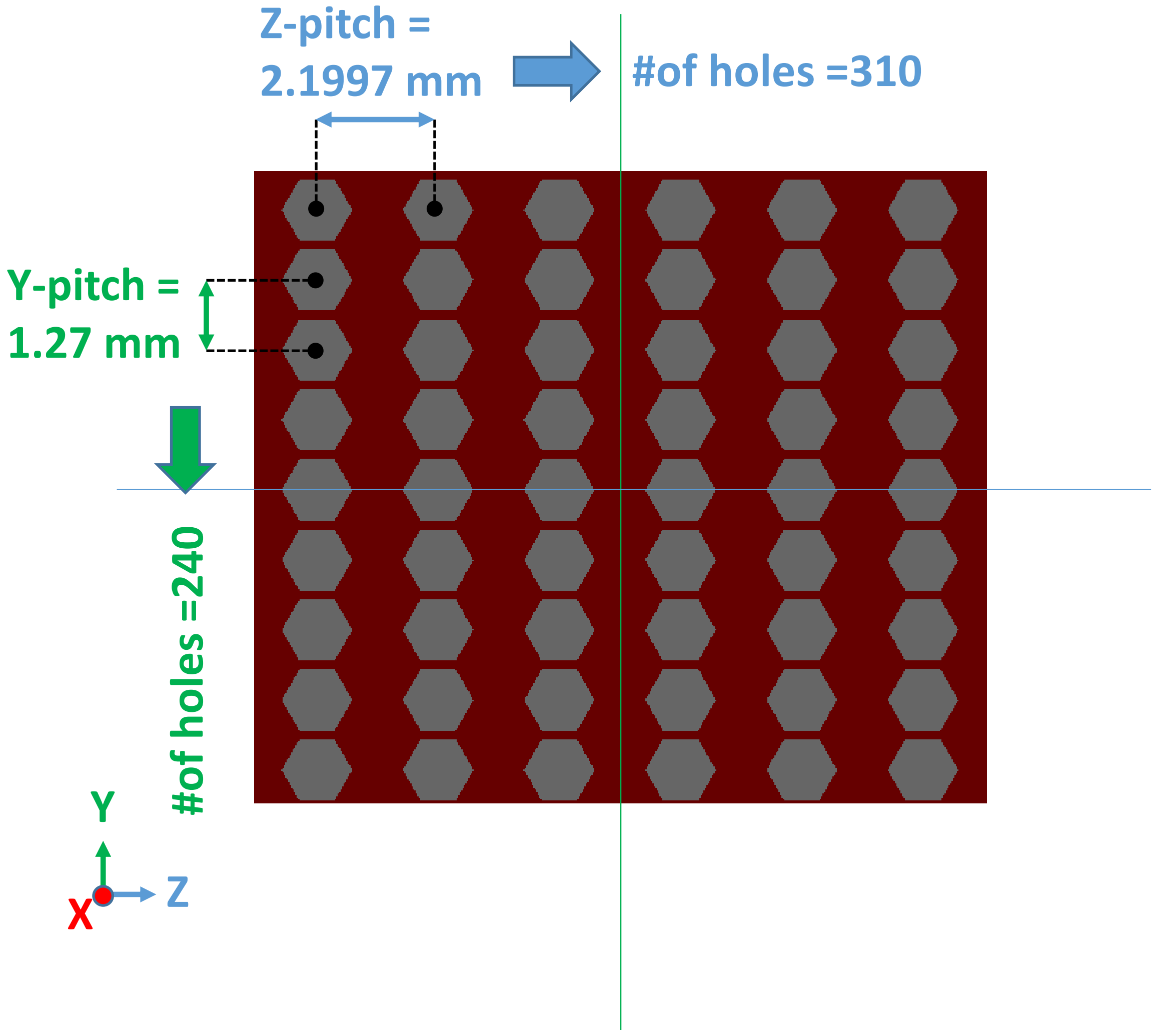
You created a single hole in YZ plane



Defining SPECT collimator (hole)

```
# ========================================
# Repeat the hole in an array
# ========================================
/gate/hole/repeaters/insert cubicArray
/gate/hole/cubicArray/setRepeatNumberX 1
/gate/hole/cubicArray/setRepeatNumberY 310
/gate/hole/cubicArray/setRepeatNumberZ 240
/gate/hole/cubicArray/setRepeatVector 0.0   1.27    2.1997 mm
```

X Y Z



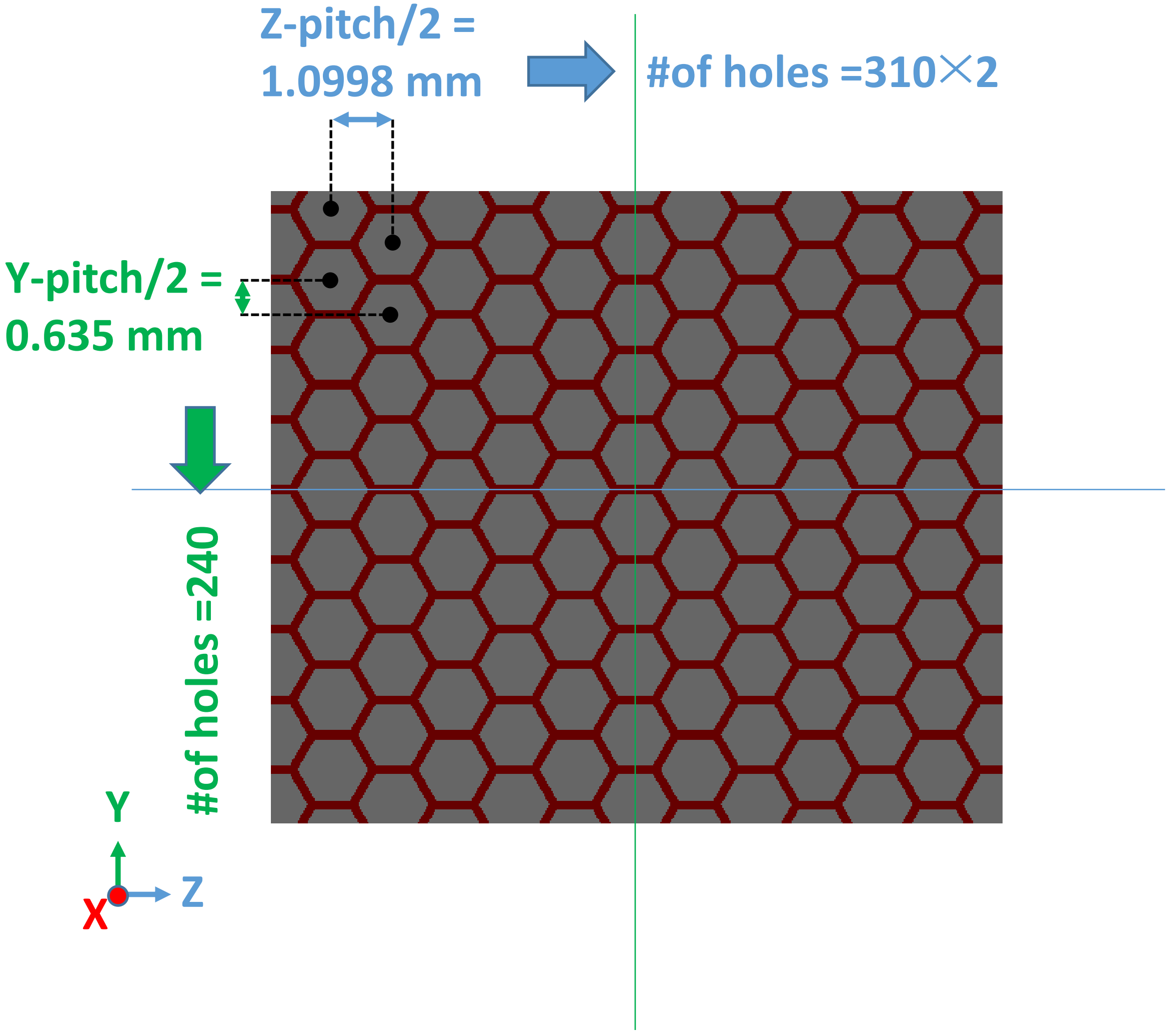
Defining SPECT collimator (hole)

```
# ========================================
# Repeat the hole in an array
# ========================================
/gate/hole/repeaters/insert cubicArray
/gate/hole/cubicArray/setRepeatNumberX 1
/gate/hole/cubicArray/setRepeatNumberY 310
/gate/hole/cubicArray/setRepeatNumberZ 240
/gate/hole/cubicArray/setRepeatVector 0.0   1.27    2.1997 mm

# ========================================
# Repeat these holes in a linear
# ========================================

/gate/hole/repeaters/insert linear
/gate/hole/linear/setRepeatNumber 2
/gate/hole/linear/setRepeatVector 0.0   0.635   1.099852 mm
```

X Y Z

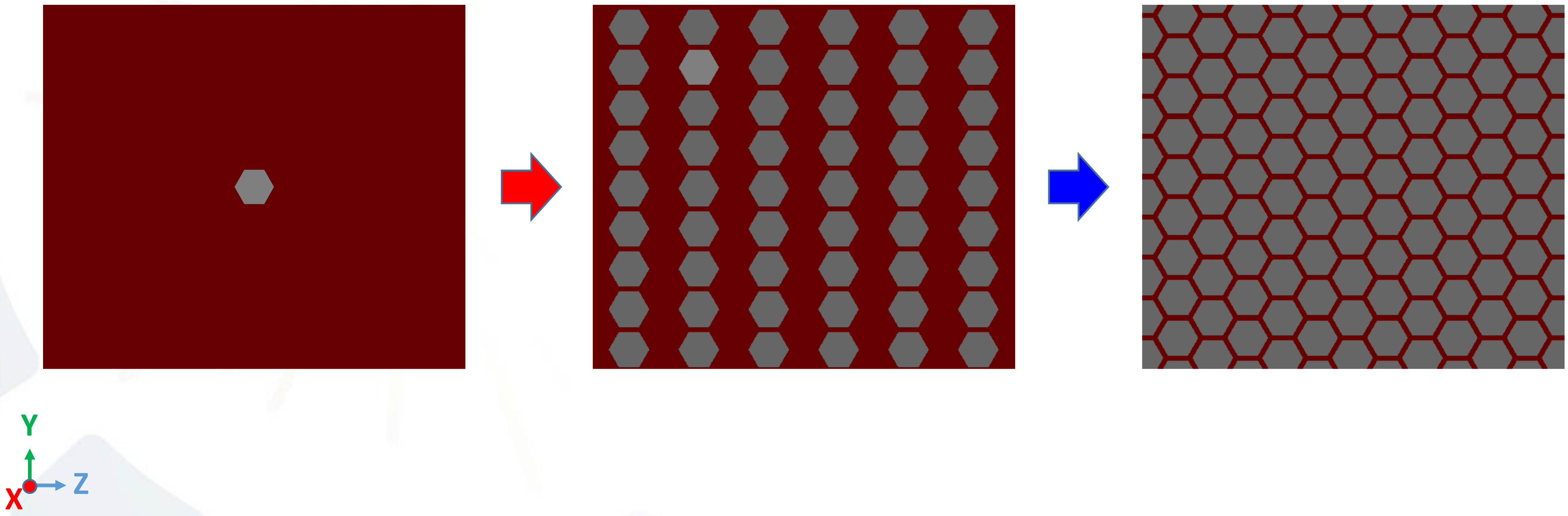


Collimator hole generation

Create a single hole

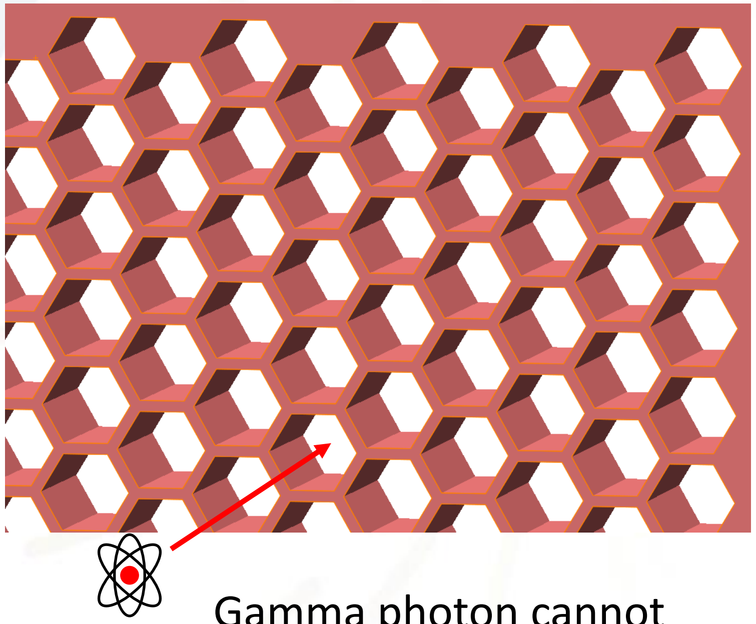
Repeater: cubicArray

Repeater: linear



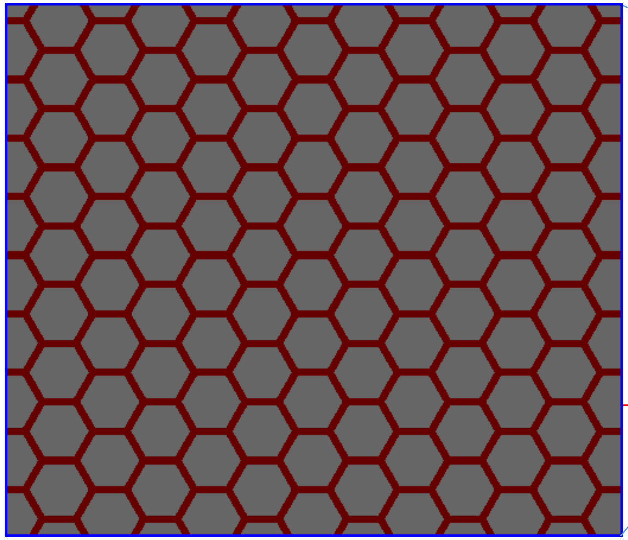
Defining SPECT collimator

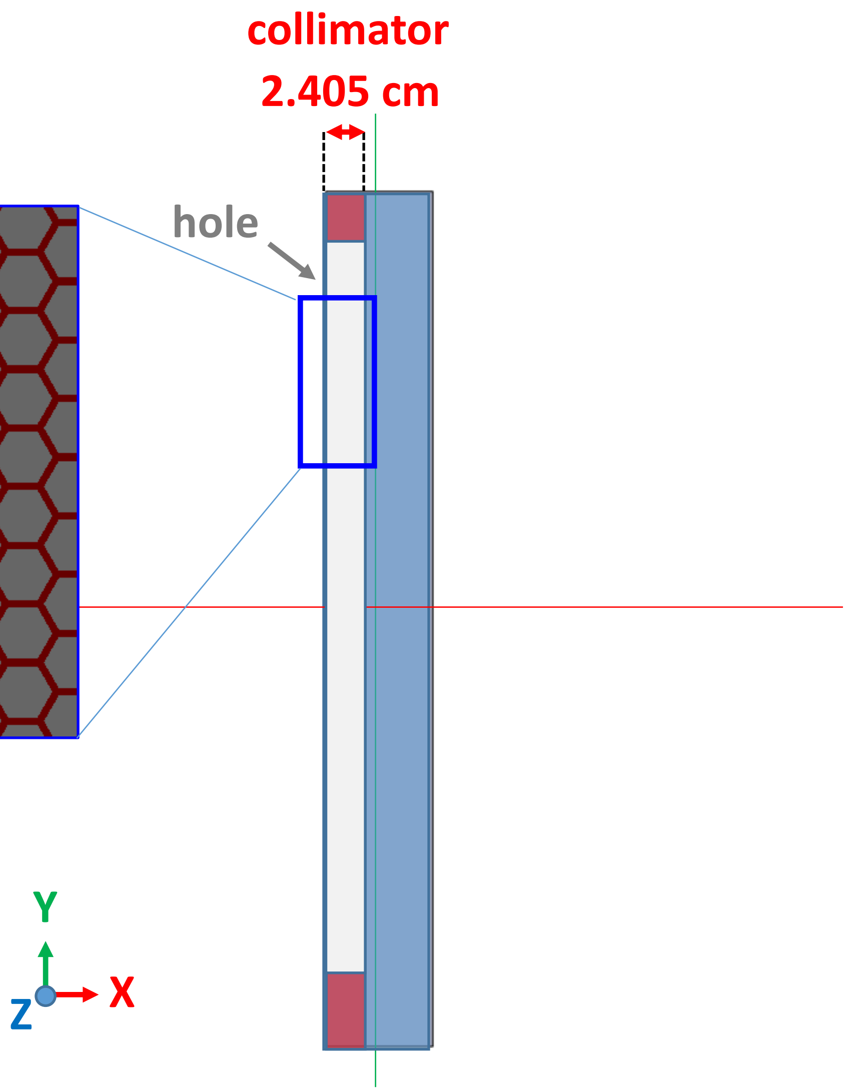
Collimator (3D view)



Gamma photon cannot pass through the hole

Collimator (2D view)





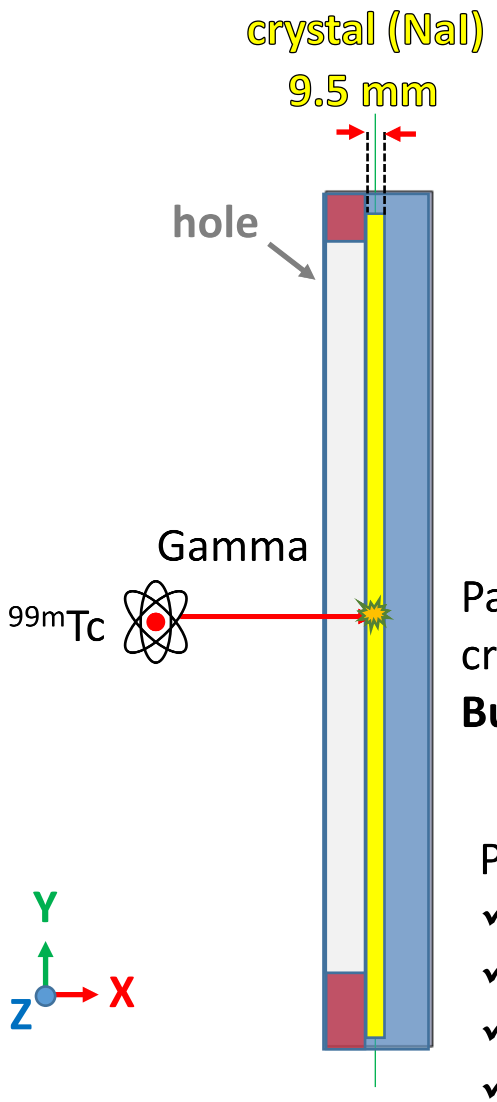
Crystal (Monolithic)

```
# =========================================
# SPECThead -> crystal (NaI) 9.5 mm
# Create the crystal volume
# =========================================

/gate/SPECThead/daughters/name crystal
/gate/SPECThead/daughters/insert box
/gate/crystal/geometry/setXLength 9.5 mm  ⇨ crystal thickness
/gate/crystal/geometry/setYLength 445 mm
/gate/crystal/geometry/setZLength 591 mm
/gate/crystal/placement/setTranslation  0. 0. 0. mm
/gate/crystal/setMaterial NaI  ⇨ crystal material
/gate/crystal/vis/setColor yellow
/gate/crystal/vis/forceWireframe
```

GateMaterials.db

```
NaI: d=3.67 g/cm3; n=2;  state=solid
       +el: name=Sodium ; n=1
       +el: name=Iodine ; n=1
```



Particle interacts with the crystal volume.
But, NO recording.

Particle interactions
- ✓ Photo-electric
- ✓ Compton scattering
- ✓ Par production
- ✓ And so on

Crystal (Crystal Sensitive Detector)

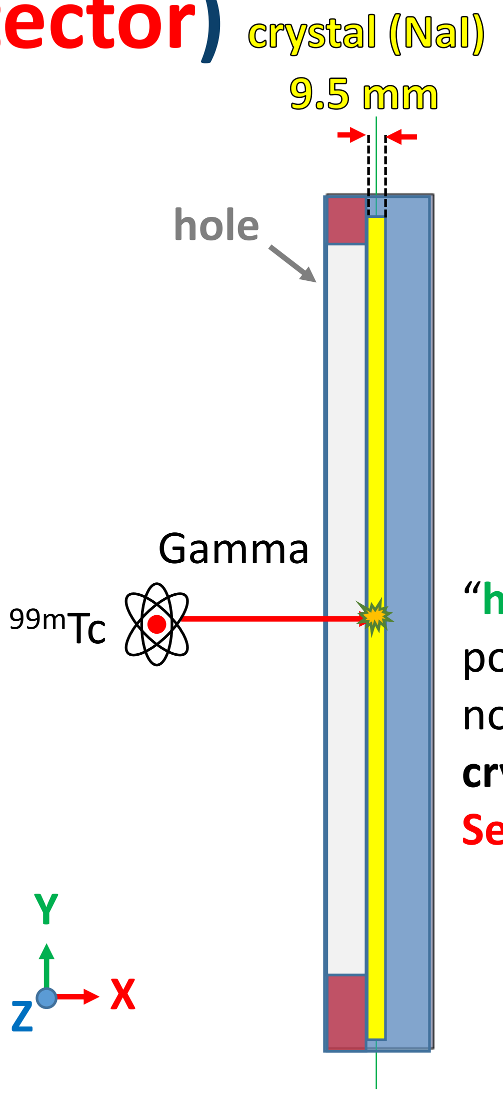
```
# ========================================
# SPECThead -> crystal (NaI) 9.5 mm
# Create the crystal volume
# ========================================

/gate/SPECThead/daughters/name crystal
/gate/SPECThead/daughters/insert box
/gate/crystal/geometry/setXLength 9.5 mm
/gate/crystal/geometry/setYLength 445 mm
/gate/crystal/geometry/setZLength 591 mm
/gate/crystal/placement/setTranslation  0. 0. 0. mm
/gate/crystal/setMaterial NaI
/gate/crystal/vis/setColor yellow
/gate/crystal/vis/forceWireframe

# (IMPORTANT) Attach Sensitive Detectors to the crystal
/gate/crystal/attachCrystalSD
```

Volume name

Record the "hit" data (energy, position, time, …)
[MeV] [mm] [s]



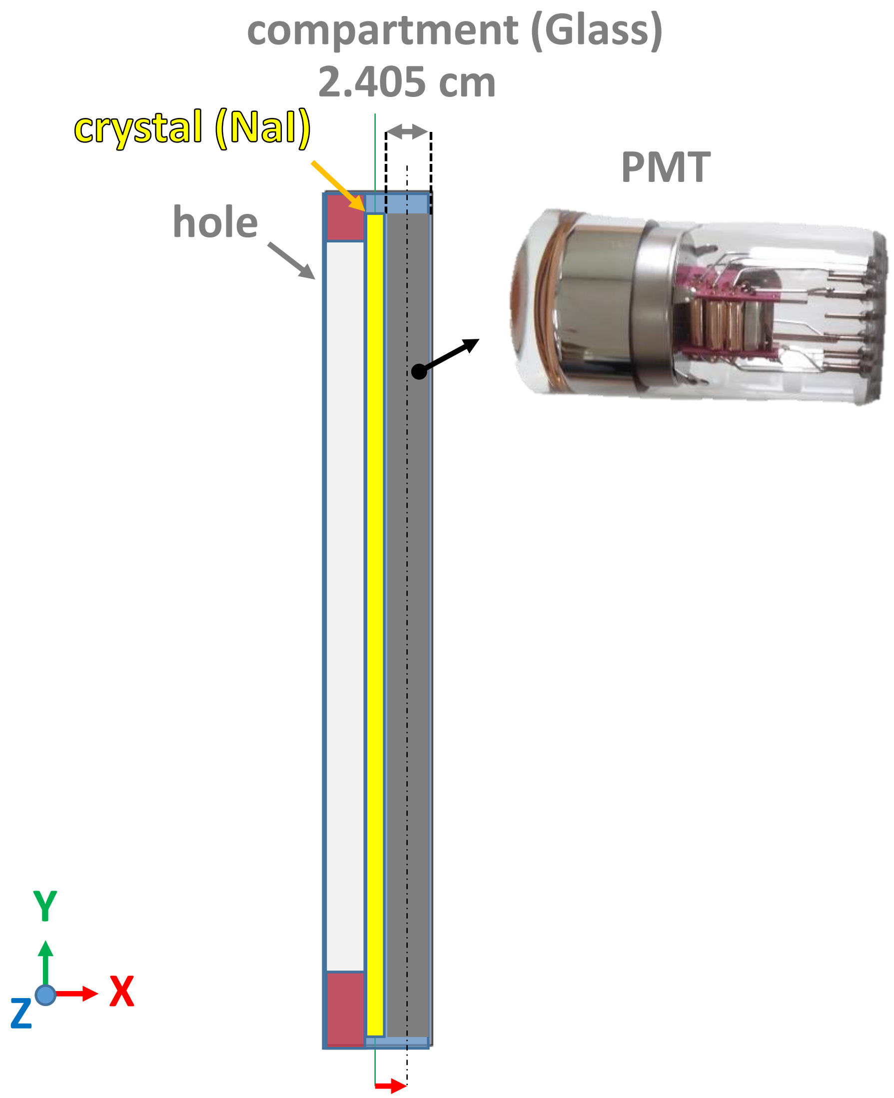
"**hit**" data (energy, position, time, …) is now **recorded** on the **crystal volume** by the **Sensitive Detector!**

Back-compartment (PMT)

```
# ========================================
# SPECThead -> compartment
# BACK-COMPARTMENT
# Create the back-compartment volume
# ========================================

/gate/SPECThead/daughters/name compartment
/gate/SPECThead/daughters/insert box
/gate/compartment/geometry/setXLength 2.405 cm
/gate/compartment/geometry/setYLength  44.5 cm
/gate/compartment/geometry/setZLength 59.1 cm
/gate/compartment/placement/setTranslation  16.775   0    0 mm
/gate/compartment/setMaterial Glass
/gate/compartment/vis/setColor grey
#/gate/compartment/vis/forceWireframe
/gate/compartment/vis/forceSolid
```

PMT is made up glass which acts
as a backscattering material



Translate the compartment **1.6775 cm** in X-dir.

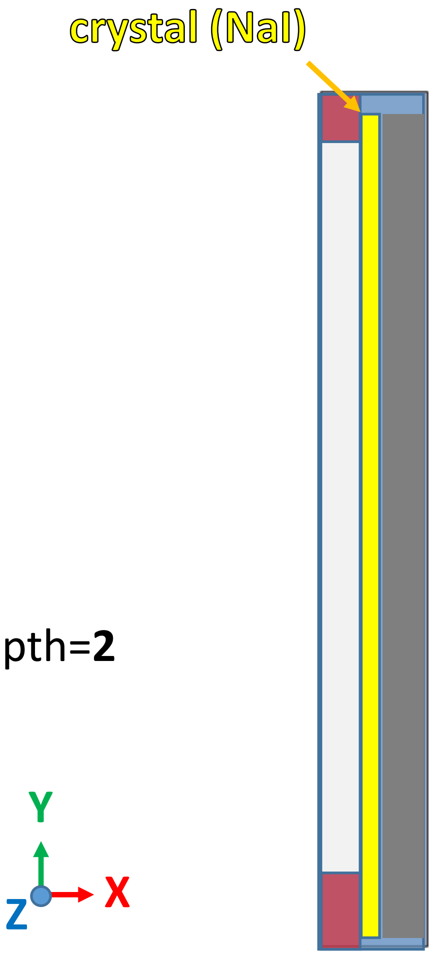
System attachment (IMPORTANT)

```
# ========================================
# S Y S T E M
# ========================================
/gate/systems/SPECThead/crystal/attach crystal ➡ Volume name
/gate/systems/SPECThead/describe ➡ Print out the SPECT info.
```

The **SPECThead system** is made of **three levels**:

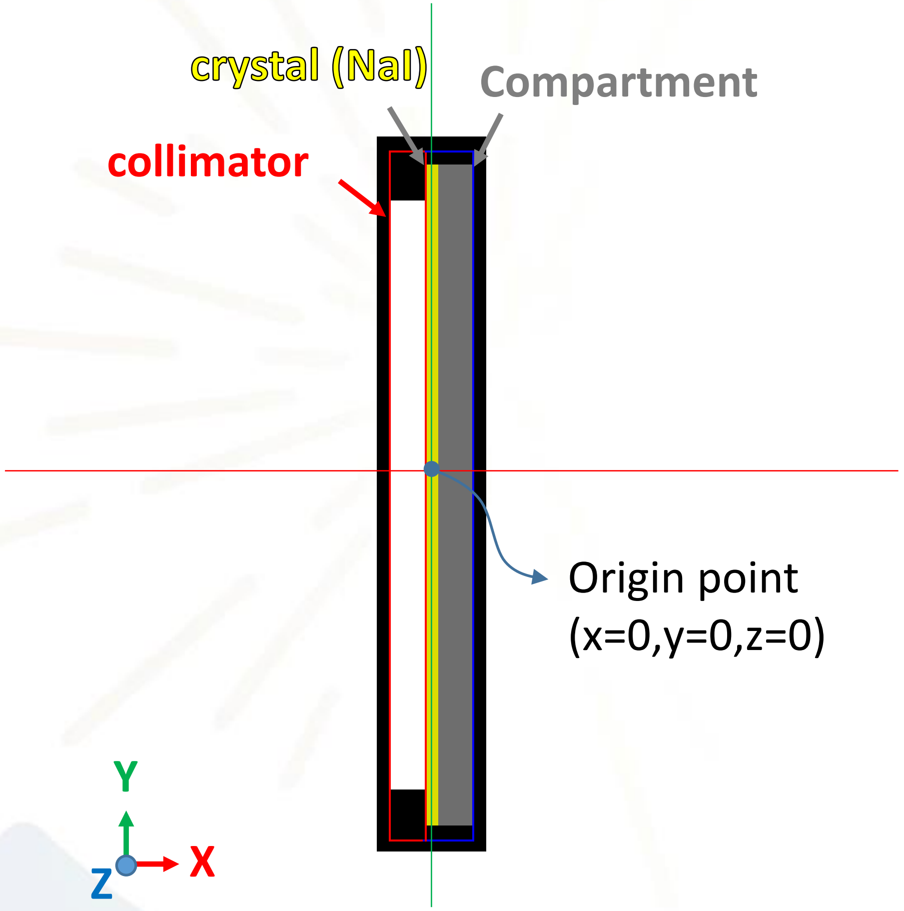
1. **base** (for the head): setDepth=**0**
2. crystal (for the crystal and crystal matrix): setDepth=**1**
3. **pixel** (for individual crystals for pixellated gamma camera): setDepth=**2**

(**IMPORTANT**) The **crystal volume** should be attached to the **SPECThead** system for the data recording

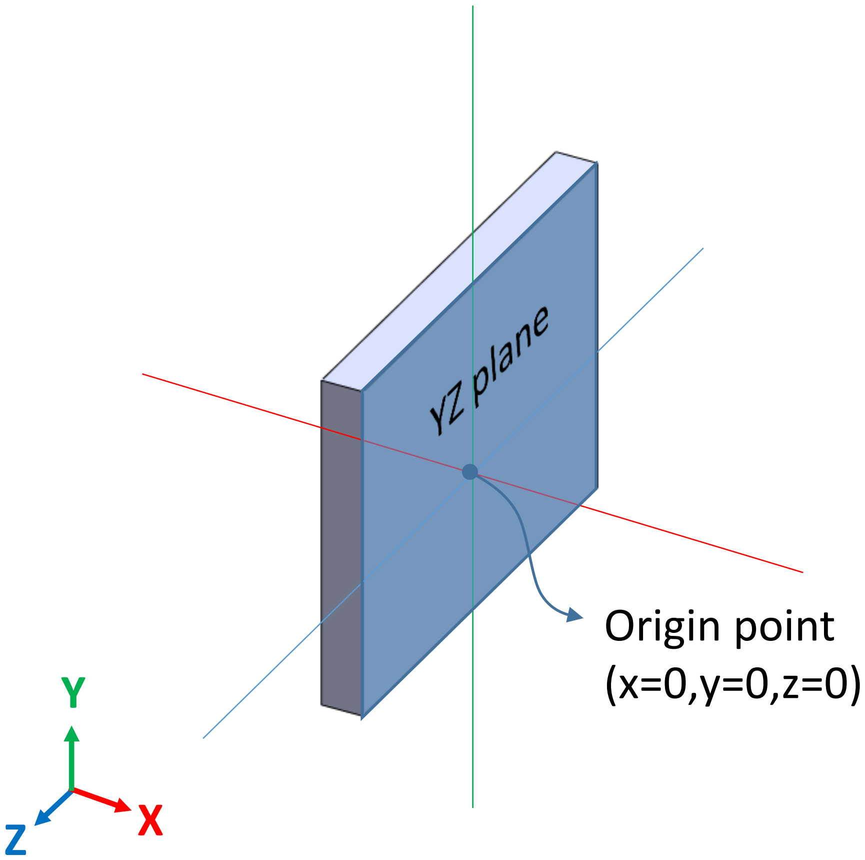


Positioning of the SPECThead

You NEED to move the SPECThead from the center of the coordinate to place phantom



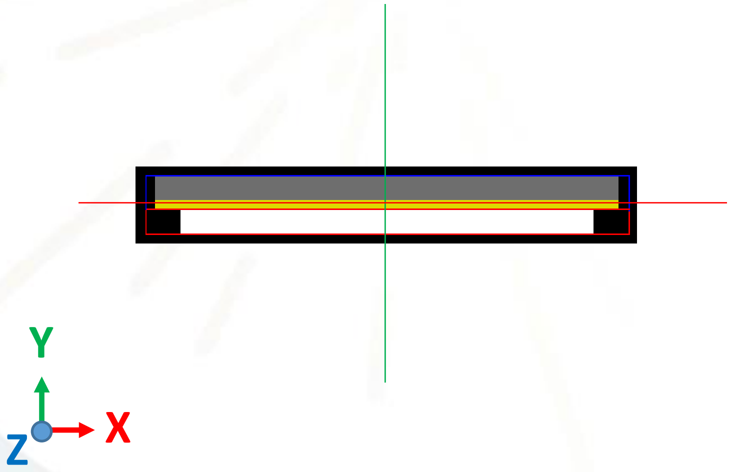
SPECThead is located at the origin of the coordinate

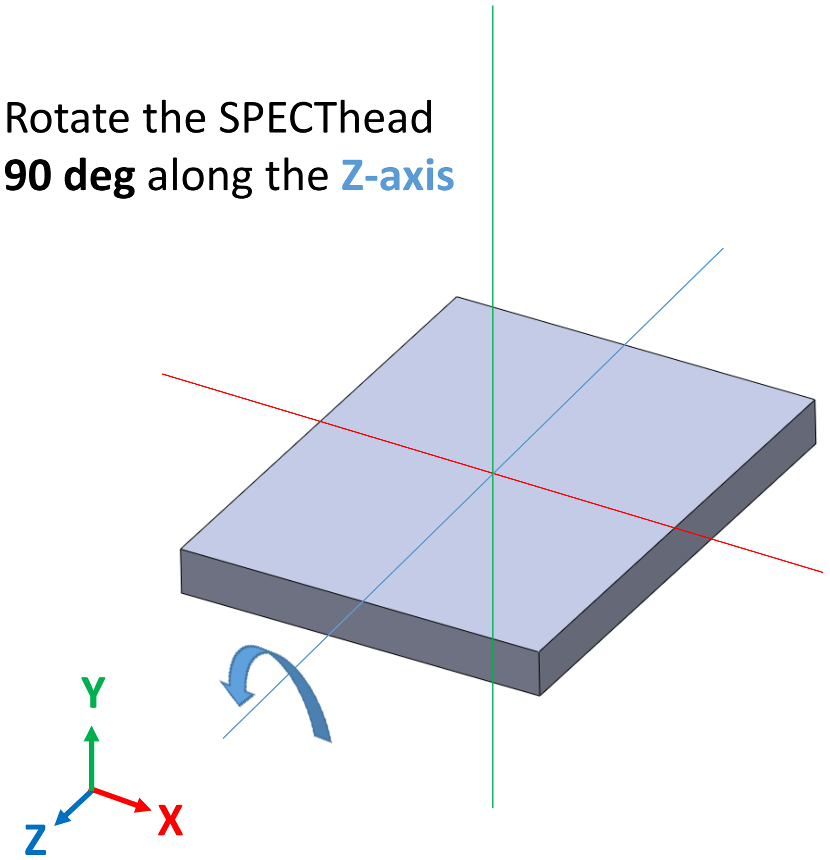


Defining a SPECT system (SPECThead)

```
# ==========================================================
# SPECThead (Rotation)
# ==========================================================
# In order to set the start angle as 0 degree for STIR reconstruction
# SPECT head rotation in -90 degree in Z-axis
/gate/SPECThead/placement/setRotationAxis   0   0   1
/gate/SPECThead/placement/setRotationAngle 90 deg
```

Rotate the SPECThead
90 deg along the **Z-axis**

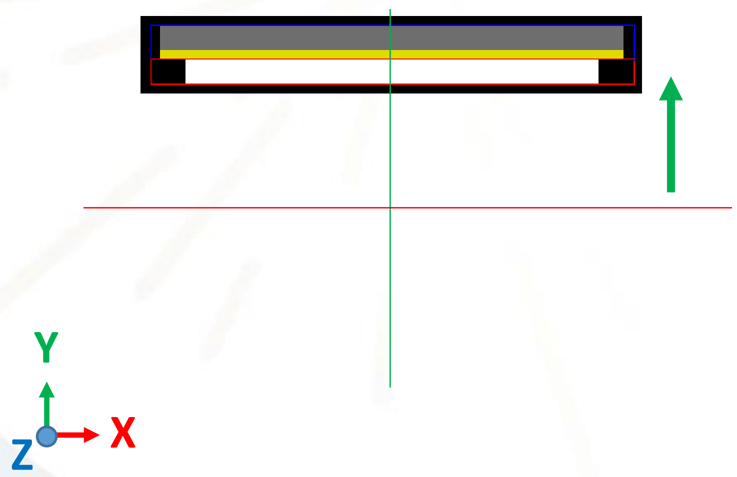




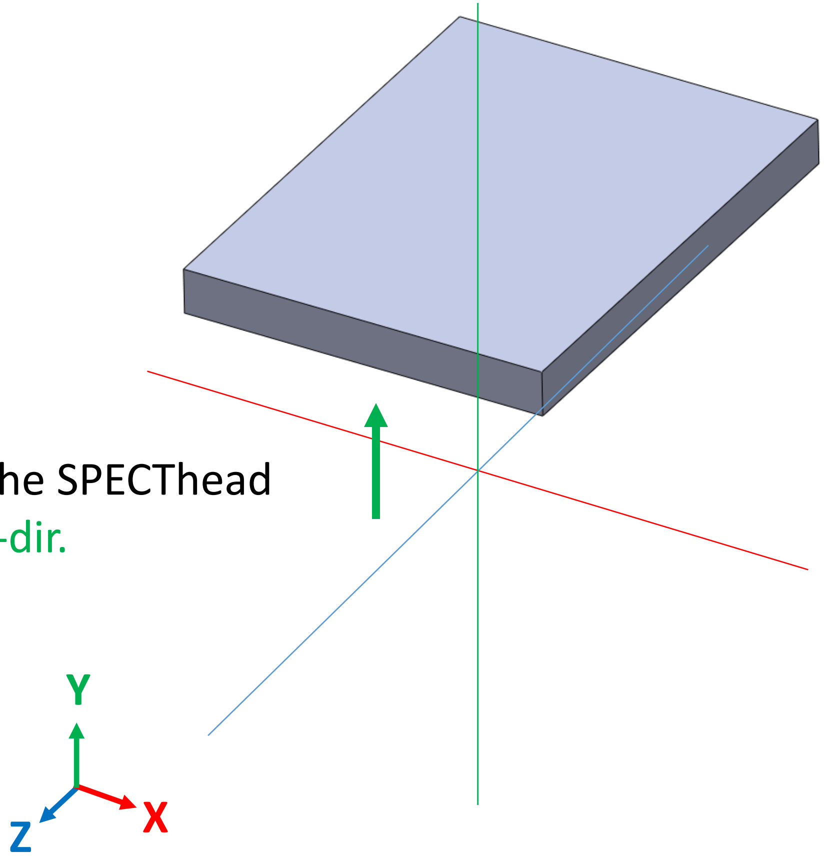
Defining a SPECT system (SPECThead)

```
# ==========================================================
# SPECThead (Translation in Y-dir.)
# ==========================================================
/gate/SPECThead/placement/setTranslation  0   20   0 cm
```

X Y Z



Translate the SPECThead
20 cm in Y-dir.



Orbiting the SPECT head in counter-clockwise

```
# ============================================================
# SPECThead (Orbiting) CW:clockwise, CCW:Counter-clockwise
# ============================================================
/gate/SPECThead/moves/insert orbiting

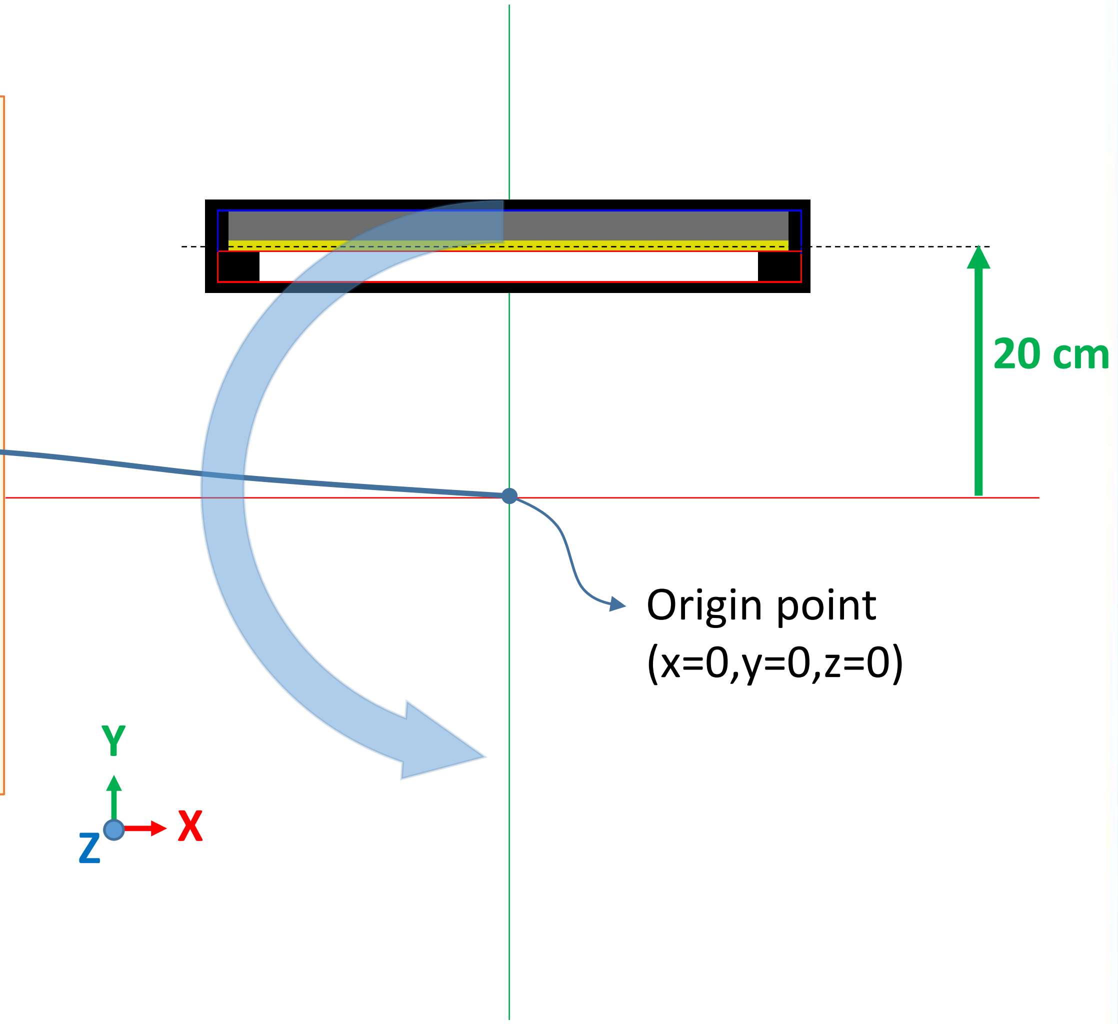
/gate/SPECThead/orbiting/setSpeed 2.8125 deg/s

/gate/SPECThead/orbiting/setPoint1  0  0  0 cm

# Counter-Clockwise(CCW) rotation (Orbit on Z-axis)
/gate/SPECThead/orbiting/setPoint2  0  0  1  cm

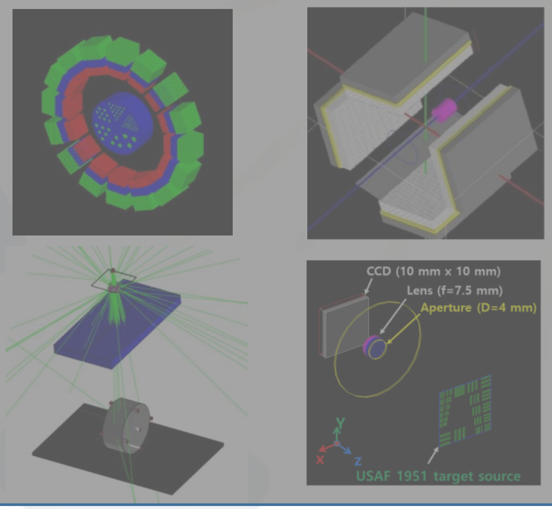
# Clockwise(CW) rotation (Orbit on Z-axis)
#/gate/SPECThead/orbiting/setPoint2  0  0  -1  cm
```

Orbiting speed



STEP 3> Define the phantom and source

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on



STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

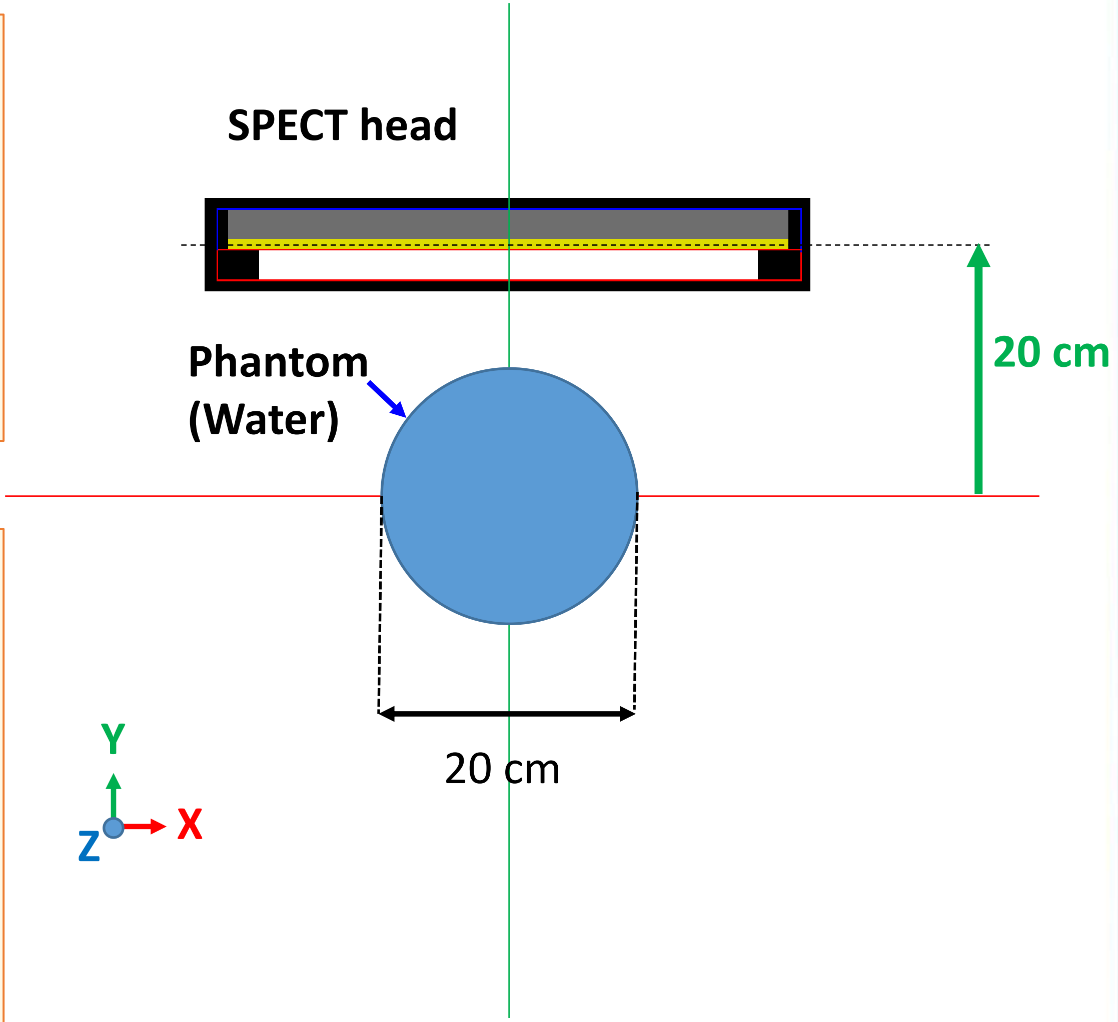
STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

Define the phantom (Attenuation material)

```
# ========================================
# PHANTOM
# Create the phantom volume
# ========================================
# Water Phantom (Rmax 10 cm)(D=20 cm)
/control/execute ./macro/Phantom_Water.mac
```

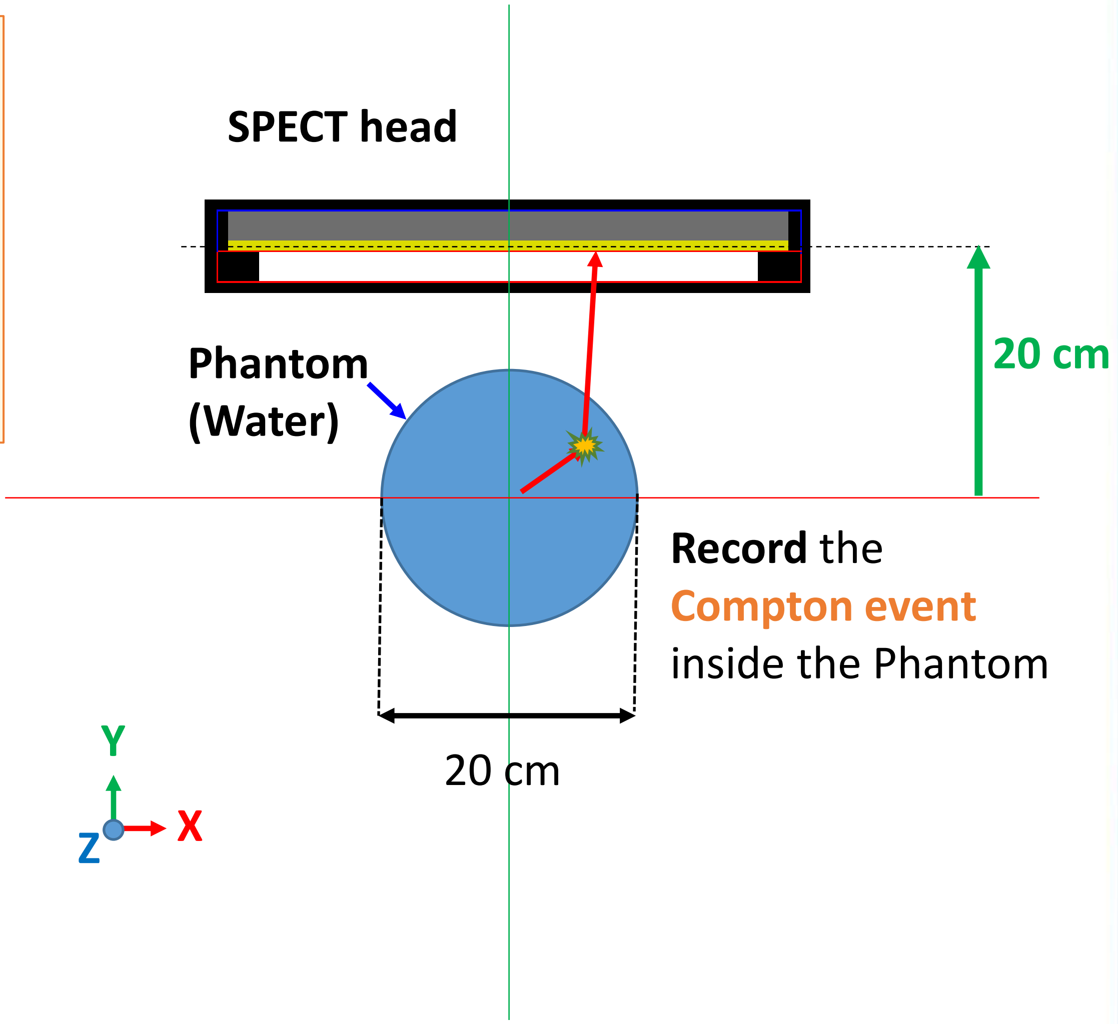
```
/gate/world/daughters/name Phantom
/gate/world/daughters/insert cylinder
/gate/Phantom/geometry/setRmax 10.  cm
/gate/Phantom/geometry/setRmin 0. cm
/gate/Phantom/geometry/setHeight 20. cm
/gate/Phantom/placement/setTranslation 0. 0. 0. cm
/gate/Phantom/setMaterial Water
/gate/Phantom/vis/setColor blue
#/gate/Phantom/vis/forceWireframe
/gate/Phantom/vis/forceSolid
/gate/Phantom/vis/setVisible 1
```



Define the phantom (Phantom Sensitive Detector)

```
# ========================================
# PHANTOM
# Create the phantom volume
# ========================================
# Water Phantom (Rmax 10 cm)(D=20 cm)
/control/execute ./macro/Phantom_Water.mac

# Record the Compton event inside the Phantom
/gate/Phantom/attachPhantomSD
```

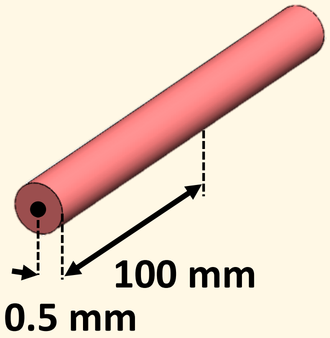


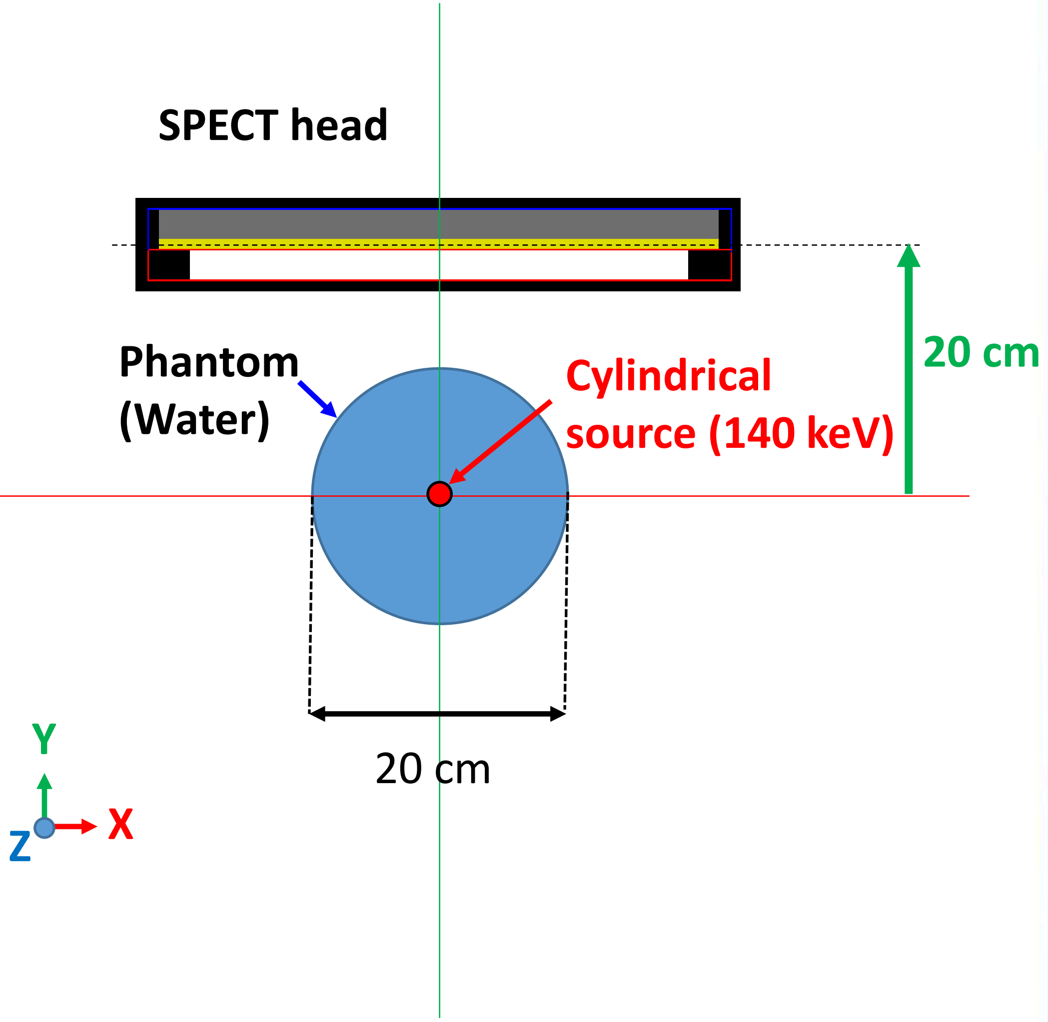
Define the source (140 keV)

```
# ===================================
# Ssource (140 keV)
# ===================================
/control/execute ./macro/Source_Cylinder_140keV_1MBq_Center.mac
```

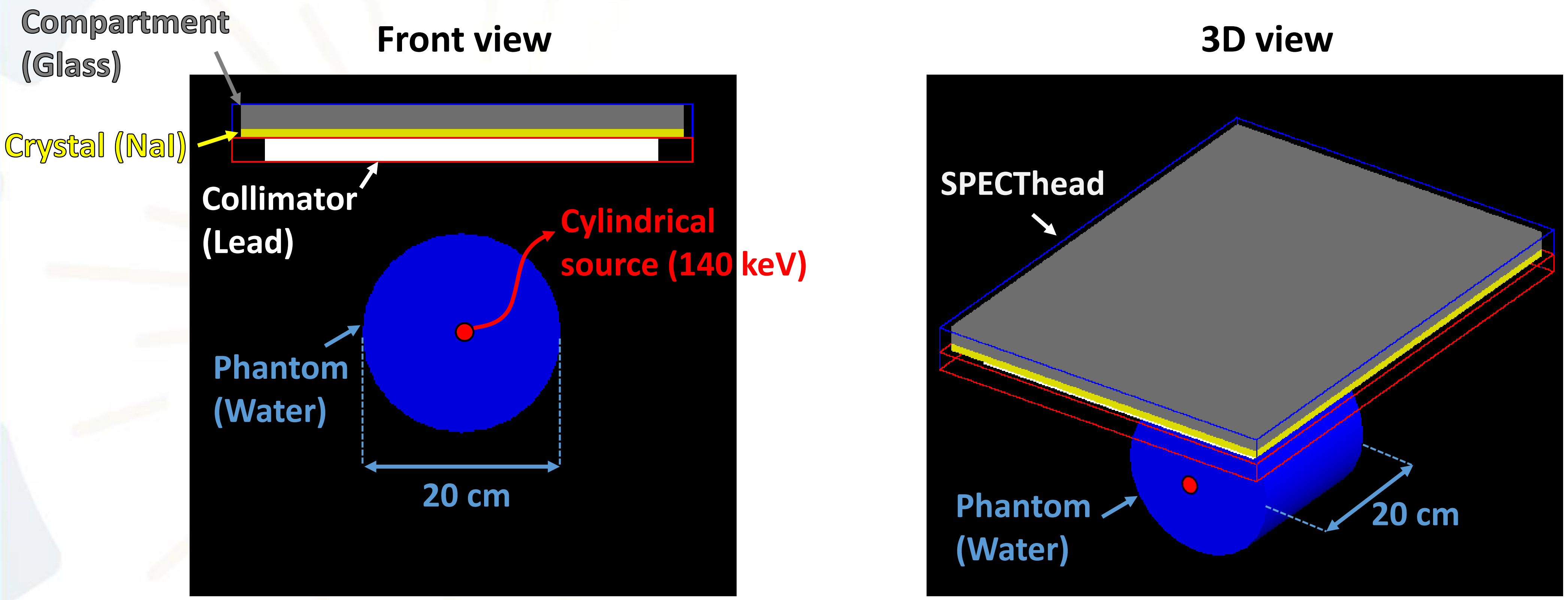
```
/gate/source/addSource mySource_1
/gate/source/mySource_1/gps/type Volume
/gate/source/mySource_1/gps/shape Cylinder
/gate/source/mySource_1/gps/radius 0.5 mm
/gate/source/mySource_1/gps/halfz 100 mm
/gate/source/mySource_1/gps/centre 0. 0. 0. cm
/gate/source/mySource_1/gps/particle gamma
/gate/source/mySource_1/gps/energy 140. keV
#  1 MBq
/gate/source/mySource_1/setActivity 1000000 Bq
# Emission angle: isotropic
/gate/source/mySource_1/gps/angtype iso

/gate/source/list
```



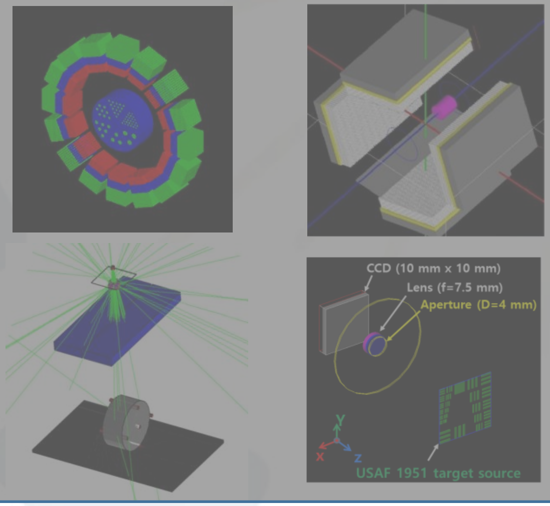


SPECThead and Phantom in GATE



STEP 4> Physics list setting

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on



STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

STEP 4> Physics list setting (GATEv6.2)

```
#=====================================================
# P H Y S I C S
#=====================================================
/gate/physics/addProcess PhotoElectric
/gate/physics/processes/PhotoElectric/setModel StandardModel

/gate/physics/addProcess Compton
/gate/physics/processes/Compton/setModel PenelopeModel

/gate/physics/addProcess RayleighScattering
/gate/physics/processes/RayleighScattering/setModel PenelopeModel

/gate/physics/addProcess ElectronIonisation
/gate/physics/processes/ElectronIonisation/setModel StandardModel e-

/gate/physics/addProcess Bremsstrahlung
/gate/physics/processes/Bremsstrahlung/setModel StandardModel e-

/gate/physics/addProcess eMultipleScattering e-

/gate/physics/processList Enabled
/gate/physics/processList Initialized
```

RayleighScattering:
No energy transfer to material.
Only scattering of photons by free electrons.

STEP 4> Physics list setting (from GATEv7.0)

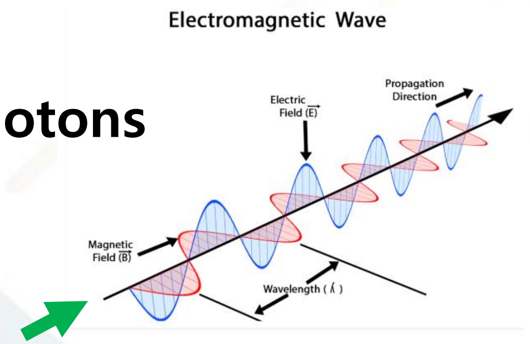
```
#=====================================================
# P H Y S I C S
#=====================================================
/gate/physics/addPhysicsList                emstandard_opt4
```

Electromagnetic standard

STEP 4> Physics list of Geant4.10.00.p2

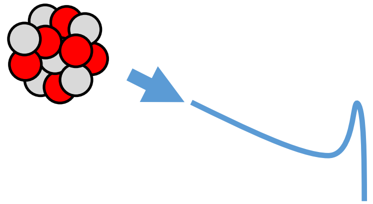
- **Electromagnetic** physic-list builder name:
  - ✓ **emstandard**
  - ✓ emstandard_opt1
  - ✓ emstandard_opt2
  - ✓ **emstandard_opt3** ➡ **Low energy EM (Medical)**
  - ✓ **emlivermore** ➡ **Low energy EM**
  - ✓ emlivermore_polar
  - ✓ **empenelope** ➡ **Low energy EM**

Photons



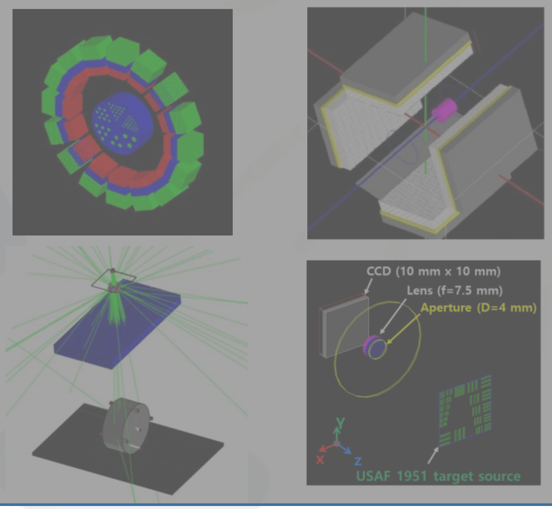
- **Hadronic** physic-lists builder name:
  - ✓ QGSP
  - ✓ QGSP_EMV
  - ✓ QGSC
  - ✓ QGSC_EMV
  - ✓ QGSP_EFLOW
  - ✓ QGSP_BERT
  - ✓ **QGSP_BERT_**EMV ➡ **Proton Bragg-peak**
  - ✓ QGSP_BERT_HP ➡ **Neutron**
  - ✓ QGSP_BERT_TRV
  - ✓ QGSP_BIC
  - ✓ QGSP_BIC_HP
  - ✓ QGSP_NEQ
  - ✓ QGSP_EMV_NQE
  - ✓ QGSP_BERT_NQE
  - ✓ QGSP_INCLXX
  - ✓ FTFP_BERT
  - ✓ FTFP
  - ✓ FTFP_EMV

Particles



STEP 5> Initialization

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on



STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

STEP 5> Initialization (IMPORTANT!)

```
# ==================================
# ! I N I T I A L I Z A T I O N !
# ==================================
/gate/run/initialize
```

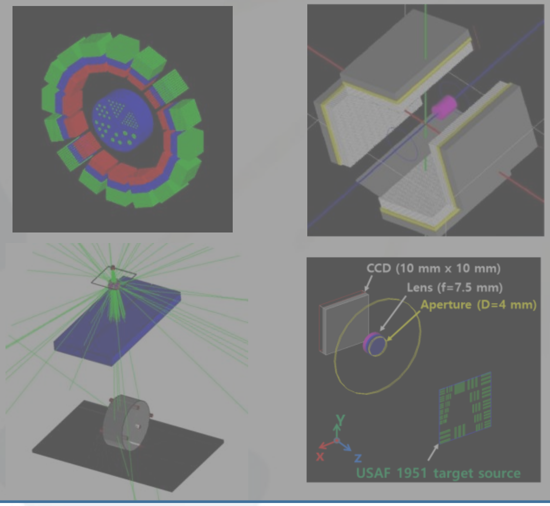
Compute cross-section tables for particles.

(IMPORTANT) You **CANNOT** change the following AFTER the "**Initialization**"

- ✓ Scanner geometry
- ✓ Phantom geometry
- ✓ Physics process

STEP 6> Digitizer setting

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on



STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

What is digitizer in GATE?

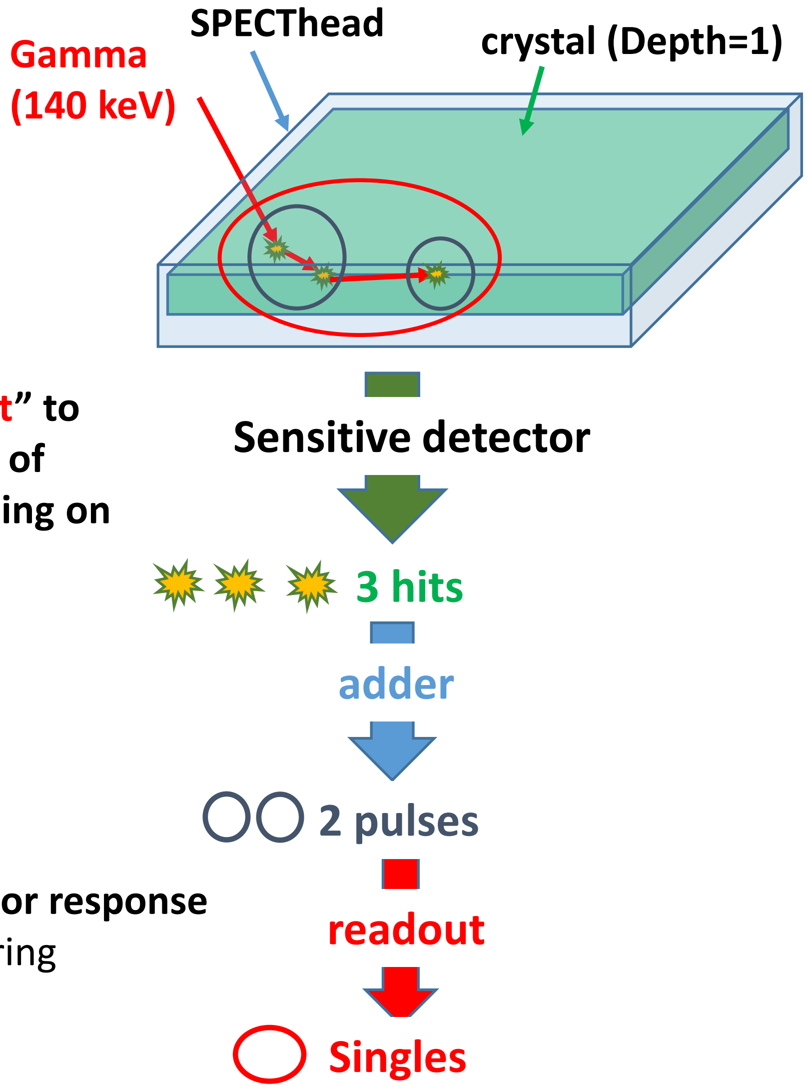
Digitizer collects the hits inside the Sensitive Detector

```
#=====================
# D I G I T I Z E R
#=====================
# Adder
/gate/digitizer/Singles/insert adder

# Readout (crystal = Depth 1)
/gate/digitizer/Singles/insert readout
/gate/digitizer/Singles/readout/setDepth 1
```

1. **Hits are added by "adder" to form a pulse per volume**

2. **The pulses are added by "read out" to form a "Singles" event (The number of readout pulses are different depending on the "setDepth")**



System	Possible Geometry	Attach Keyword Argument	Depth for readout
SPECThead	Geometry no fixed	crystal	1
		Pixel	2

Energy : The total sum energy deposited inside the volume of the readout depth
Position : The interaction position of the most highest gamma photon energy (winner-takes-all)

Readout with **detector response**
- Energy, spatial blurring
- Thresholder
- Dead time

Digitizer setting

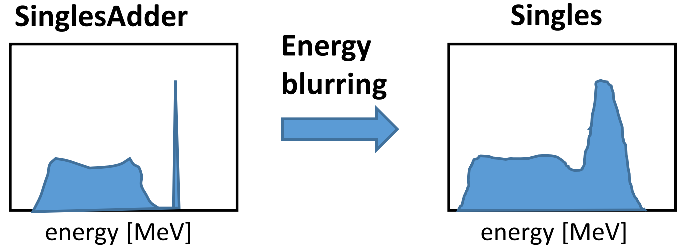
```
# Energy blurring
/gate/digitizer/Singles/insert blurring
/gate/digitizer/Singles/blurring/setResolution 0.10
/gate/digitizer/Singles/blurring/setEnergyOfReference 140. keV
```

```
# Spatial blurring (Intrinsic spatial resolution)
/gate/digitizer/Singles/insert spblurring
/gate/digitizer/Singles/spblurring/setSpresolution 3.8 mm
```

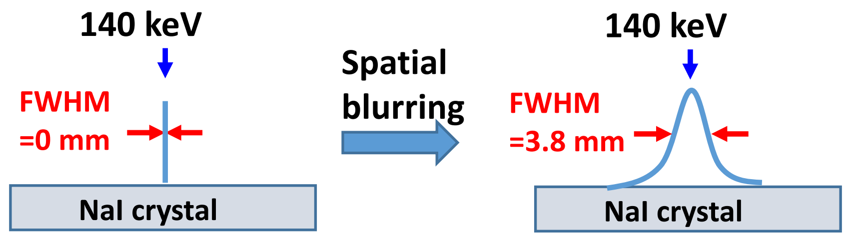
```
# Energy cut
/gate/digitizer/Singles/insert thresholder
/gate/digitizer/Singles/thresholder/setThreshold 126. keV
/gate/digitizer/Singles/insert upholder
/gate/digitizer/Singles/upholder/setUphold 154. keV
```

Energy resolution (10%)

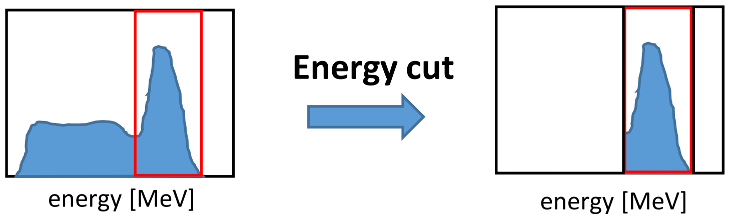
Energy blurring of **10%** with respect to **140 keV** is applied as the **pulses** are added to form a **Singles event**



Intrinsic spatial resolution (3.8 mm)

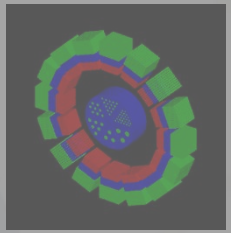
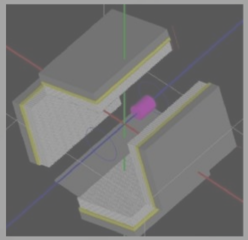
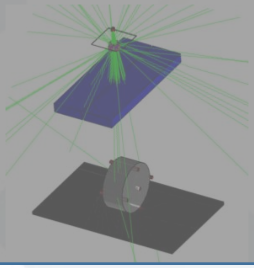
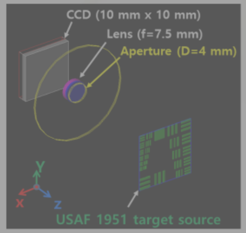


Energy cut (126-154 keV)



STEP 7> Choose your output format

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on

STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

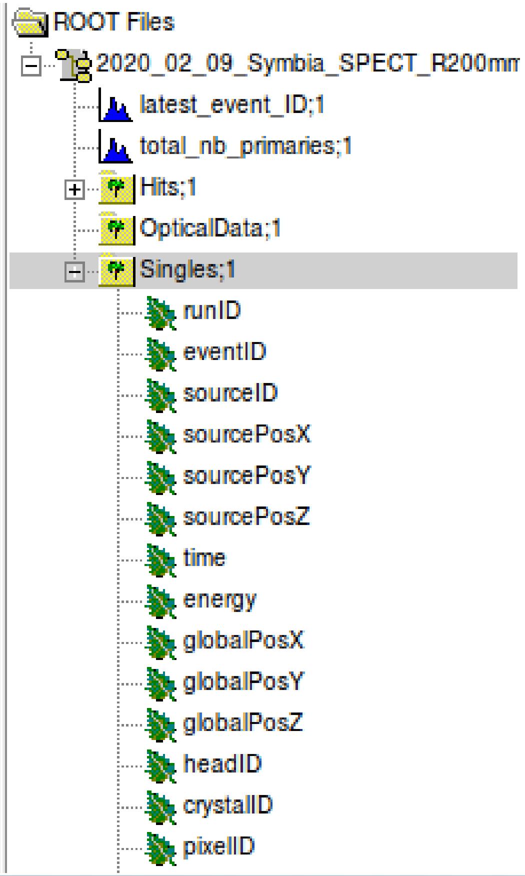
Choose your output format (ROOT)

```
#==============================
# D A T A   O U T P U T   (ROOT)
#==============================
/gate/output/root/enable
/gate/output/root/setFileName    SPECT_output

#/gate/output/root/setRootSinglesAdderFlag 1
#/gate/output/root/setRootSinglesSpblurringFlag 1
#/gate/output/root/setRootSinglesBlurringFlag 1
#/gate/output/root/setRootSinglesSpblurringFlag 1
#/gate/output/root/setRootSinglesThresholderFlag 1
```

ROOT output   SPECT_output.**root**

Energy, position, time, and so on



You can analyze the data with ROOT code (C++)
(But, you need some knowledge of ROOT)

Choose your output format (ASCII)

```
#=============================
# D A T A   O U T P U T   (ASCII)
#=============================
/gate/output/ascii/enable
/gate/output/ascii/setFileName    SPECT_output

#/gate/output/ascii/setOutFileSinglesAdderFlag 1
#/gate/output/ascii/setOutFileSinglesSpblurringFlag 1
#/gate/output/ascii/setOutFileSinglesBlurringFlag 1
#/gate/output/ascii/setOutFileSinglesThresholderFlag 1
#/gate/output/ascii/setOutFileSinglesUpholderFlag 1
```

ASCII output   SPECT_output**Singles**.dat

Energy, position, time and so on

You can import the data with MATLAB or other software.

	runID	eventID	sourceID	globalPosX, Y, Z [mm]						time [s]	energy [MeV]	sourcePosX, Y, Z [mm]							compVolName	RayleighVolName
1	0	9512	1	9.986e+01	4.628e-01	-2.247e+01	0	0	0	4.74626311371477427325516e-03	1.271e-01	1.032e+02	1.988e+02	-2.006e+01	0	0	0	0	NULL	NULL
2	0	12018	1	9.976e+01	1.646e-01	-2.693e+01	0	0	0	6.01566909772416943263940e-03	1.399e-01	1.008e+02	1.954e+02	-3.830e+01	0	0	0	0	NULL	NULL
3	0	23341	0	-1.337e-01	-3.969e-01	-1.187e+01	0	0	0	1.17500909420960343576557e-02	1.377e-01	2.973e+00	1.967e+02	-1.017e+01	0	0	0	0	NULL	NULL
4	0	29071	1	1.002e+02	-8.458e-02	-3.010e+01	0	0	0	1.46022930780796110494801e-02	1.386e-01	9.687e+01	2.066e+02	-3.639e+01	0	1	0	0	NULL	NULL
5	0	39851	0	-4.050e-01	2.324e-01	9.360e+00	0	0	0	1.98819188276941477555582e-02	1.384e-01	-5.056e-01	2.020e+02	1.225e+01	0	0	0	0	NULL	NULL
6	0	47865	0	-7.778e-03	1.193e-01	-9.057e+00	0	0	0	2.39211484110345880271797e-02	1.450e-01	-5.259e+00	2.007e+02	-1.406e+01	0	0	0	0	NULL	NULL
7	0	50221	1	9.981e+01	6.349e-02	6.982e+01	0	0	0	2.50796959939116846649565e-02	9.485e-02	9.615e+01	2.046e+02	7.336e+01	1	0	0	0	compartment_phys	NULL
8	0	52085	1	1.003e+02	2.041e-01	-1.546e+01	0	0	0	2.60397818196953546865391e-02	1.342e-01	9.881e+01	2.012e+02	-1.924e+01	0	0	0	0	NULL	NULL
9	0	55525	1	9.982e+01	-4.174e-01	5.926e+01	0	0	0	2.77462444159193646897599e-02	1.468e-01	1.029e+02	2.008e+02	5.395e+01	0	0	0	0	NULL	NULL
10	0	60665	1	1.001e+02	-1.009e-01	1.201e+01	0	0	0	3.03269476497537056325360e-02	1.422e-01	9.600e+01	2.029e+02	1.533e+01	0	0	0	0	NULL	NULL
11	0	61938	0	3.453e-01	-1.324e-01	9.995e+01	0	0	0	3.09670204125084211344010e-02	1.383e-01	2.805e+00	1.925e+02	9.746e+01	0	0	0	0	NULL	NULL
12	0	65329	1	9.952e+01	7.095e-03	-1.838e+01	0	0	0	3.26557664312751988466843e-02	1.498e-01	9.866e+01	1.970e+02	-1.528e+01	0	0	0	0	NULL	NULL
13	0	79812	1	9.963e+01	2.782e-01	-6.601e+01	0	0	0	3.98755792333058273202440e-02	1.407e-01	9.628e+01	2.003e+02	-5.973e+01	0	0	0	0	NULL	NULL
14	0	101045	1	9.975e+01	1.598e-01	-1.652e+01	0	0	0	5.04305389460897868225686e-02	1.346e-01	1.053e+02	2.024e+02	-1.370e+01	0	0	0	0	NULL	NULL
15	0	110034	1	1.001e+02	-3.370e-01	9.065e+01	0	0	0	5.49673717884843968106701e-02	1.456e-01	9.497e+01	2.012e+02	8.640e+01	0	0	0	0	NULL	NULL

Choose your output format (Projection)

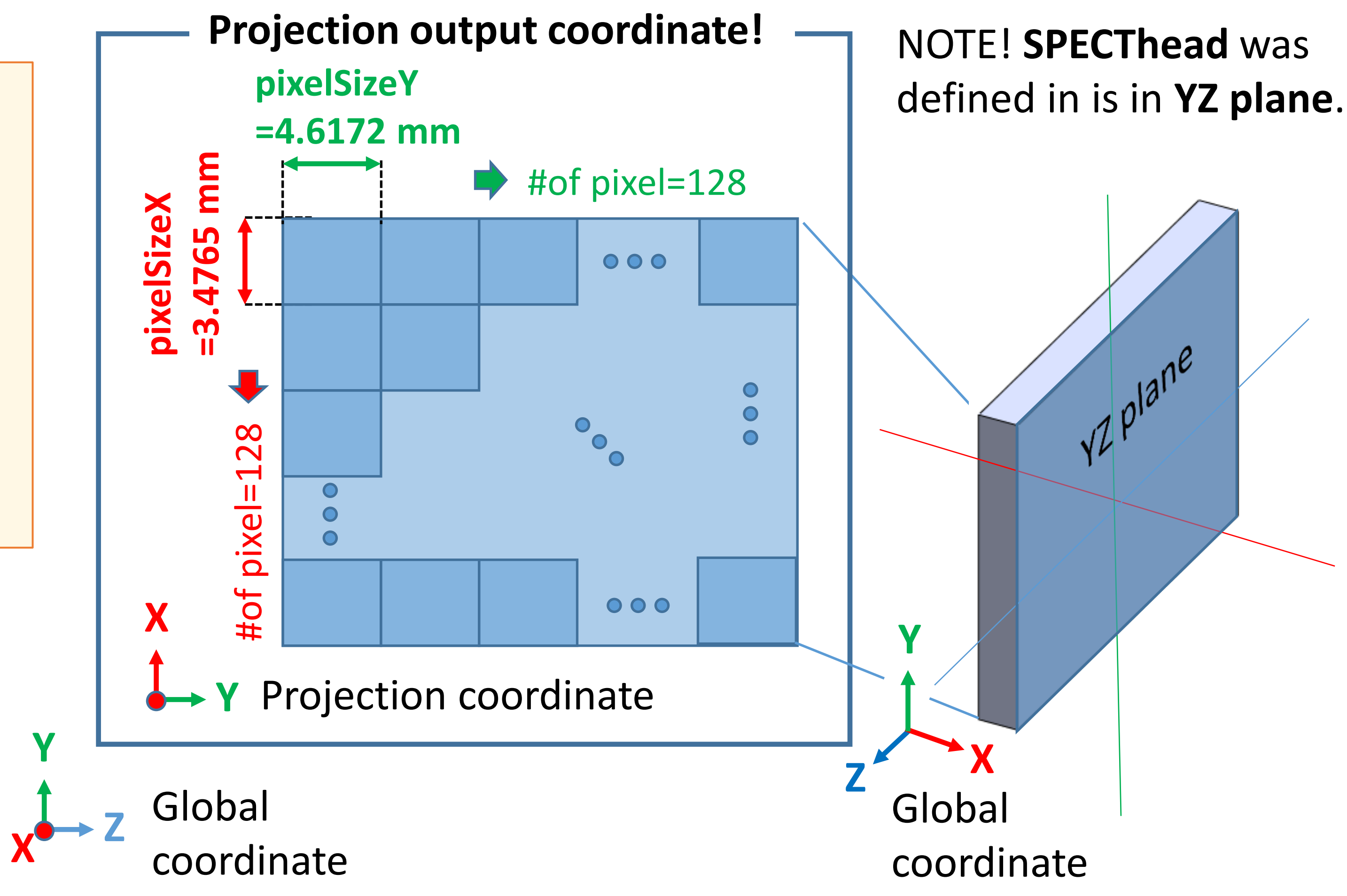
```
#======================================
# P R O J E C T I O N (Interfile)
#*.hdr(header), *.sin(Binary image projection)
#======================================
/gate/output/projection/enable
/gate/output/projection/setFileName     SPECT_output
/gate/output/projection/pixelSizeX 3.4765 mm
/gate/output/projection/pixelSizeY 4.6172 mm
/gate/output/projection/pixelNumberX 128
/gate/output/projection/pixelNumberY 128
/gate/output/projection/projectionPlane YZ
```

PixelX PixelY

Projection output (interfile format)

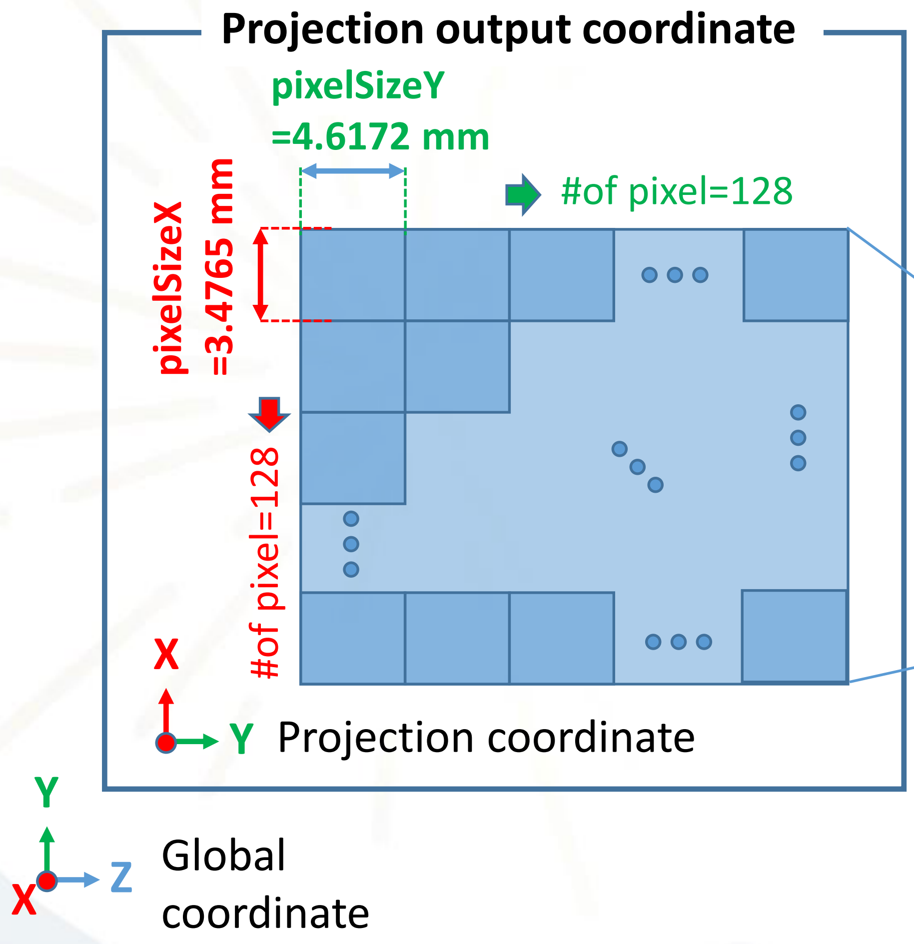
- ✓ SPECT_output.**hdr** (Header)
- ✓ SPECT_output.**sin** (Projection)

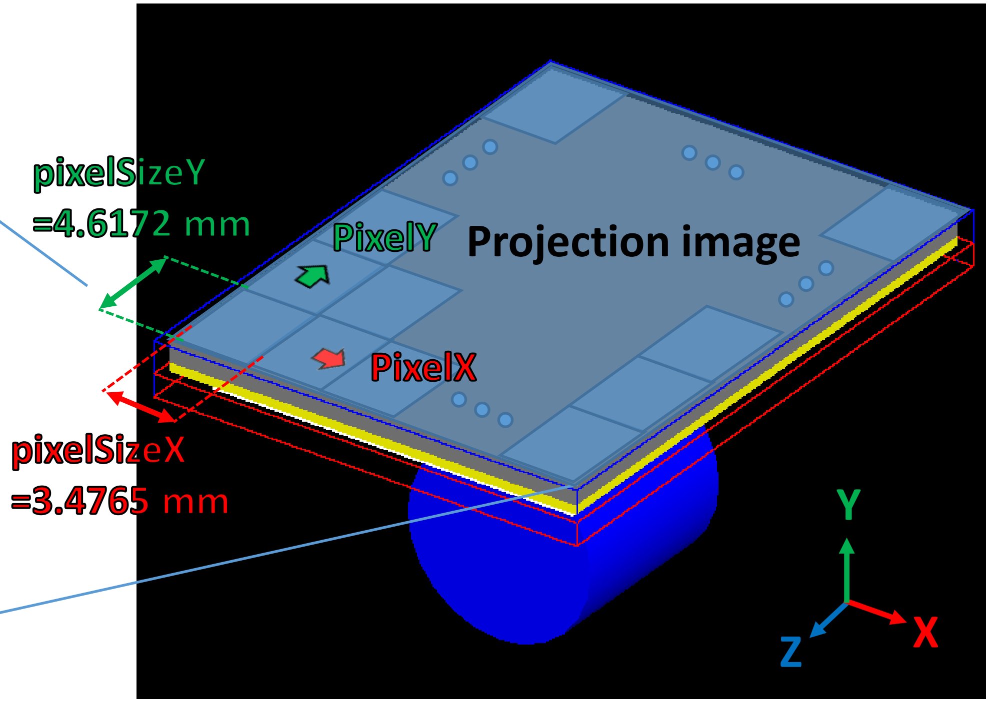
You can reconstruct the data with STIR!



NOTE! **SPECThead** was defined in is in **YZ plane**.

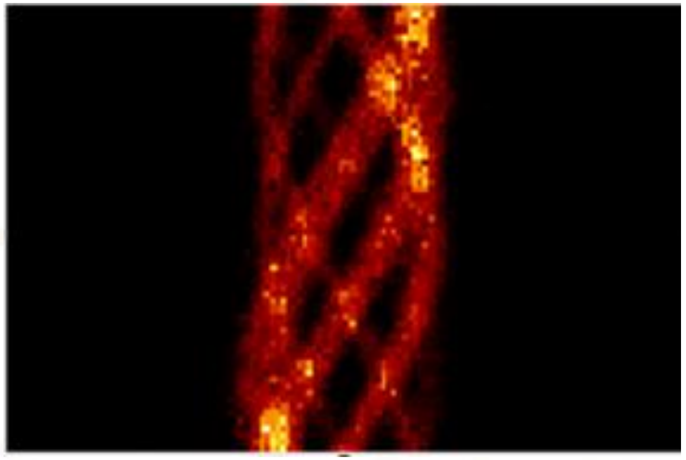
Projection output (X, Y pixel orientation)





Choose your output format (Projection)(sinogram)

GATE projection output (*.sin)



You can **open** the projection output by using **AMIDE** or **ImageJ**

You need the **header information** to open the projection output

Projection output (interfile format)

- ✓ SPECT_output.**hdr** (Header)
- ✓ SPECT_output.**sin** (Projection)

You can reconstruct the data with STIR!

Choose your output format (Projection)(Header)

Matrix size, pixel size, and data type are described in the header file.

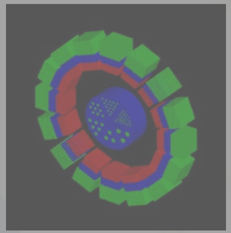
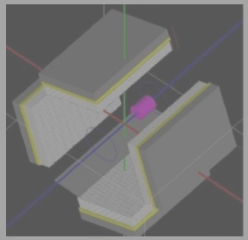
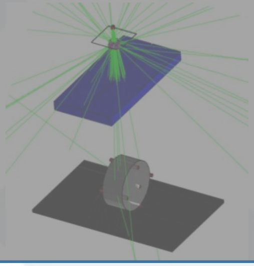
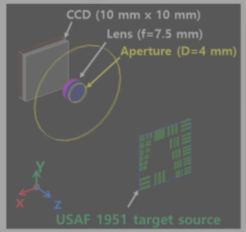
```
!INTERFILE :=
!imaging modality := nucmed
!version of keys := 3.3
date of keys := 1992:01:01
;
!GENERAL DATA :=
data description := GATE simulation
!data starting block := 0
!name of data file := SPECT_output.sin;
!GENERAL IMAGE DATA :=
!type of data := TOMOGRAPHIC
!total number of images := 64
study date := 2016:03:21
study time := 07:12:45
imagedata byte order := LITTLEENDIAN
number of energy windows := 1
;
energy window [1] := Singles
energy window lower level [1] := 126
energy window upper level [1] := 154
;
```

```
!SPECT STUDY (general) :=
number of detector heads := 1
;
!number of images/energy window := 64
!process status := Acquired
!matrix size [1] := 128
!matrix size [2] := 128
!number format := unsigned integer
!number of bytes per pixel := 2
scaling factor (mm/pixel) [1] := 3.4765
scaling factor (mm/pixel) [2] := 4.6172
!number of projections := 64
!extent of rotation := 180
!time per projection (sec) := 1
study duration (sec) := 64
!maximum pixel count := 23
;
!SPECT STUDY (acquired data) :=
!direction of rotation := CW
start angle := 0
first projection angle in data set := 0
```

```
acquisition mode := stepped
orbit := Circular
;
;GATE GEOMETRY :=
;head x dimension (cm) := 5.76
;head y dimension (cm) := 46.34
;head z dimension (cm) := 61.44
;head material := Air
;head x translation (cm) := 0
;head y translation (cm) := 20
;head z translation (cm) := 0
;crystal x dimension (cm) := 0.95
;crystal y dimension (cm) := 44.5
;crystal z dimension (cm) := 59.1
;crystal material := NaI
;
;GATE SIMULATION :=
;number of runs := 64
;
!END OF INTERFILE :=
```

STEP 8> GATE run!

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on

STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
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- OSCaR (cone-beam CT)
- In-house software

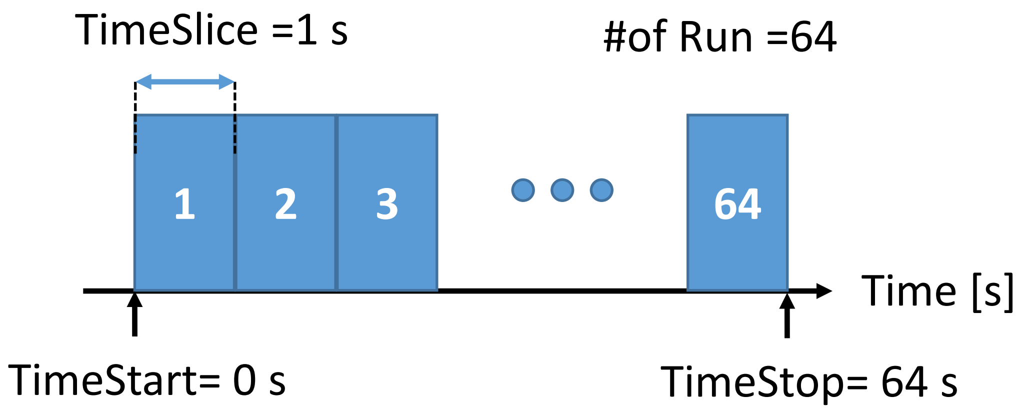
GATE Run

```
# =========================================
#   R A N D O M
# =========================================
# JamesRandom Ranlux64 MersenneTwister
/gate/random/setEngineName Ranlux64
/gate/random/setEngineSeed auto
/gate/random/verbose 1
```

```
# (Case 2) (#Proj = 64) (Rotation speed = 2.8125 deg/sec)
/gate/application/setTimeSlice     1 s
/gate/application/setTimeStart     0. s
/gate/application/setTimeStop      64 s
```

```
# ==================================================
# R U N   T H E   S I M U L A T I O N !
# ==================================================
/gate/application/startDAQ
```

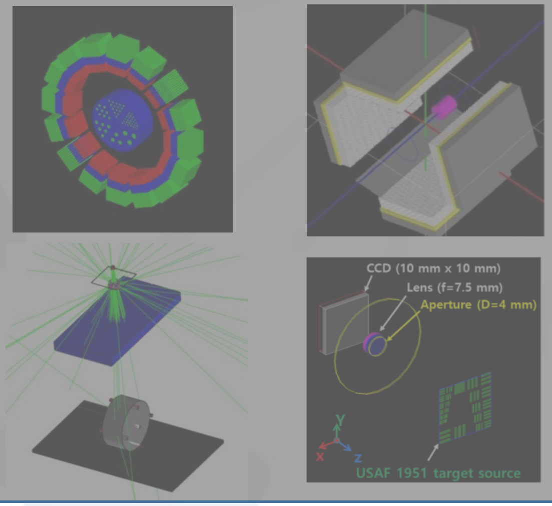
#of Projection = #of Run



$$\#\text{of Run} = \frac{setTimeStop - setTimeStart}{setTimeSlice}$$

STEP 9> Data analysis (Next session)

STEP 1> Select the system type in accordance with your imaging modality:
- ✓ PETscanner
- ✓ SPECThead
- ✓ CTscanner
- ✓ OpticalSystem
- ✓ and so on



STEP 2> Define the detector geometry:
- ✓ Crystal (attachCrystalSD)
- ✓ Collimator (for SPECT)

STEP 3> Define the phantom and source geometry:
- ✓ Phantom (attenuation)(attachPhantomSD)
- ✓ Source (Activity)

STEP 4> Physics list setting

STEP 5> Initialization

STEP 6> Digitizer setting:
- ✓ Energy resolution
- ✓ Thresholder
- ✓ Spatial blurring (for SPECT)
- ✓ Coincidence window (for PET)

STEP 7> Choose your output format
- ✓ ROOT, ASCII, Projection and so on

STEP 8> GATE run!

STEP 9> Data analysis
- ROOT
- Python
- MATLAB

STEP 10> Image reconstruction
- STIR (PET, SPECT)
- CASToR (PET, SPECT)
- OSCaR (cone-beam CT)
- In-house software

What we are going to study next

- ✓ SPECT data analysis (Planar)
- ✓ Change the collimator (LEHR -> LEAP)
- ✓ Image reconstruction using STIR

お疲れ様でした！
(質問ありませんか?)

Thank you for your kind attention!
(Any question?)

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