GATEv7.1 NIR Lens simulation with voxelized source and phantom GATEv6.2 Cerenkov imaging simulation

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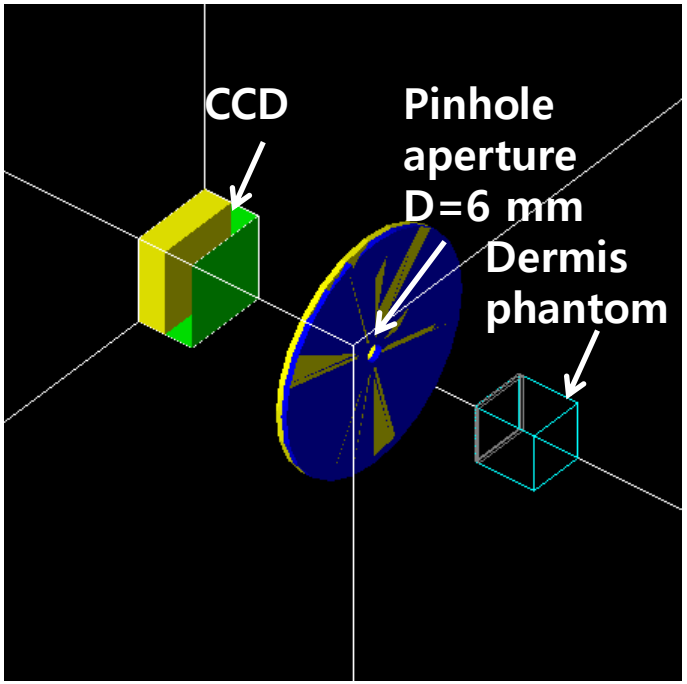
- Voxelized source (Tumor)

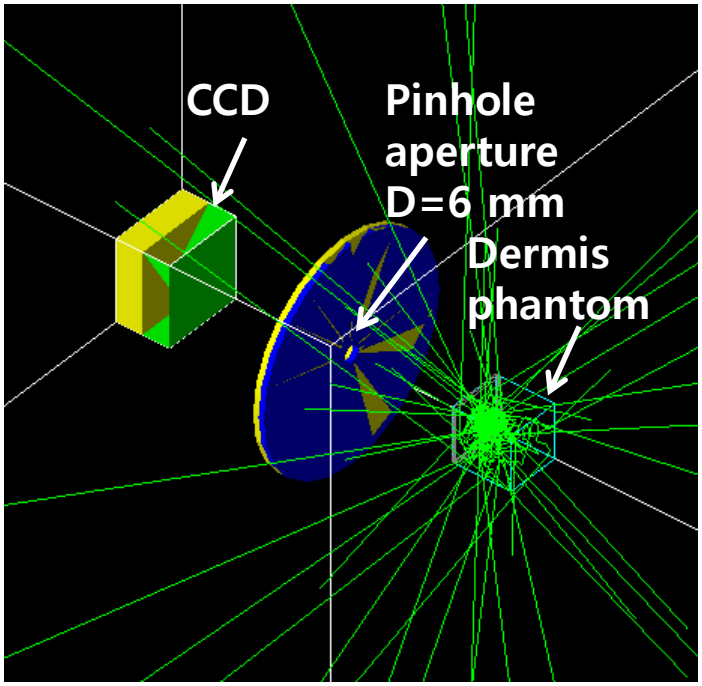
GATEv6.2 optical simulation (Cerenkov)

- Voxelized source (4 spots)

GATEv7.1 voxelized source and phantom simulation without optical lens

Bioluminescence simulation





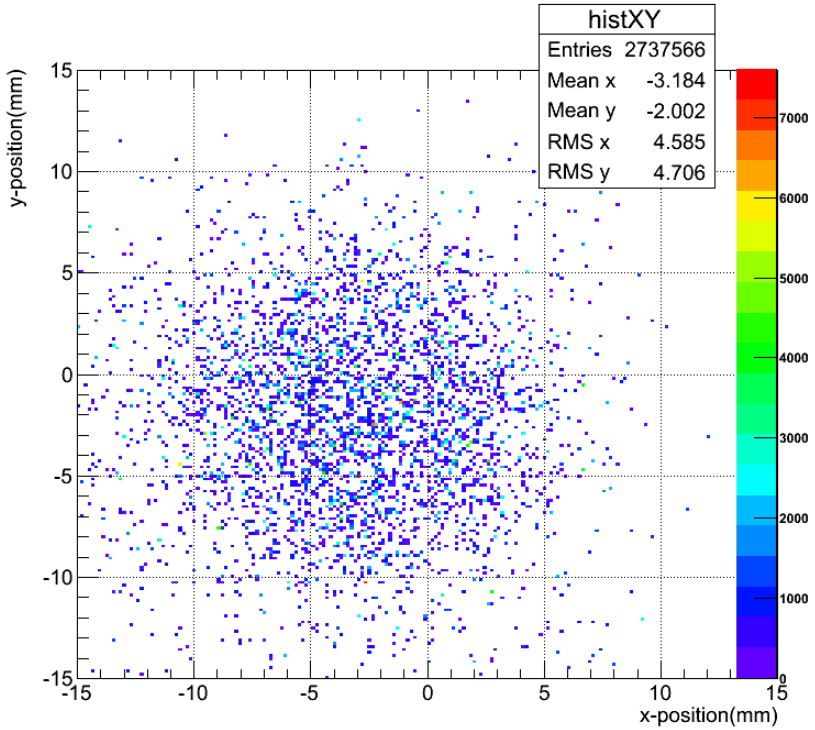
CCD
- **30x 30 mm²**
- **Material: Air**

Pinhole aperture
- **D=6 mm**

Optical Photon sources
- **Visible light** (λ=665 nm)
- **Voxelized-source (Tumor)**

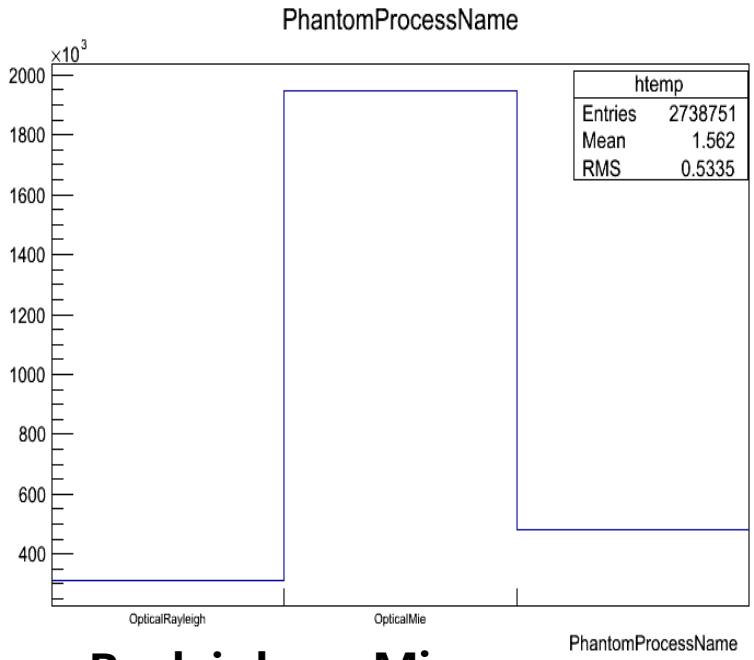
Bioluminescence simulation results

CCD image (2D)



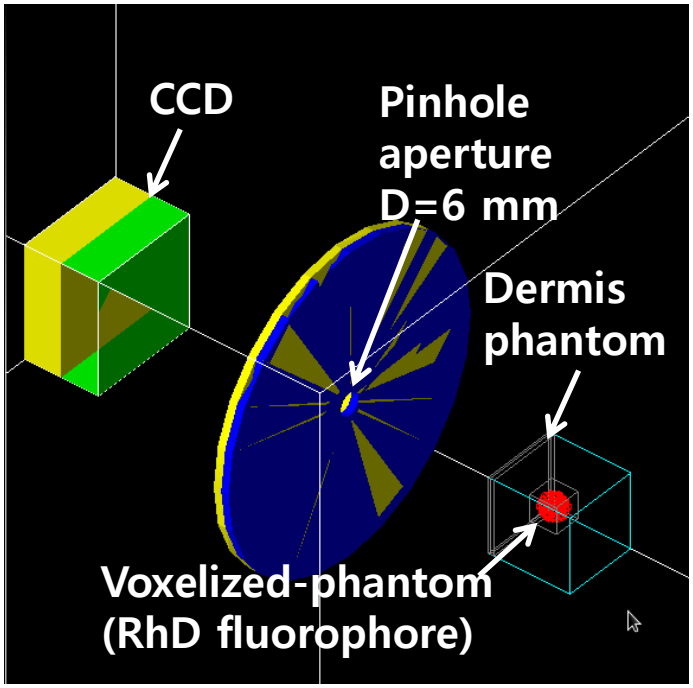
CCD size = 30 mm^2

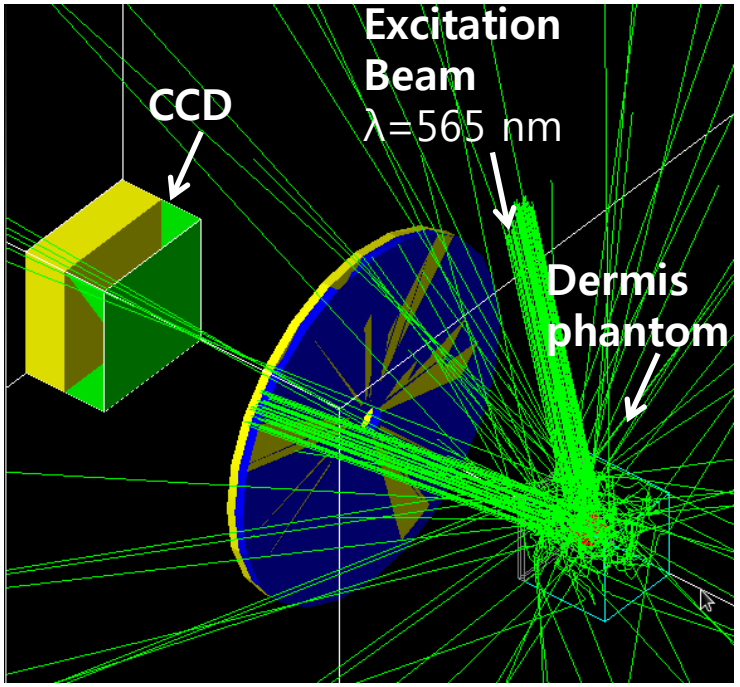
Optical Process Name



Rayleigh Mie

Fluorescence simulation





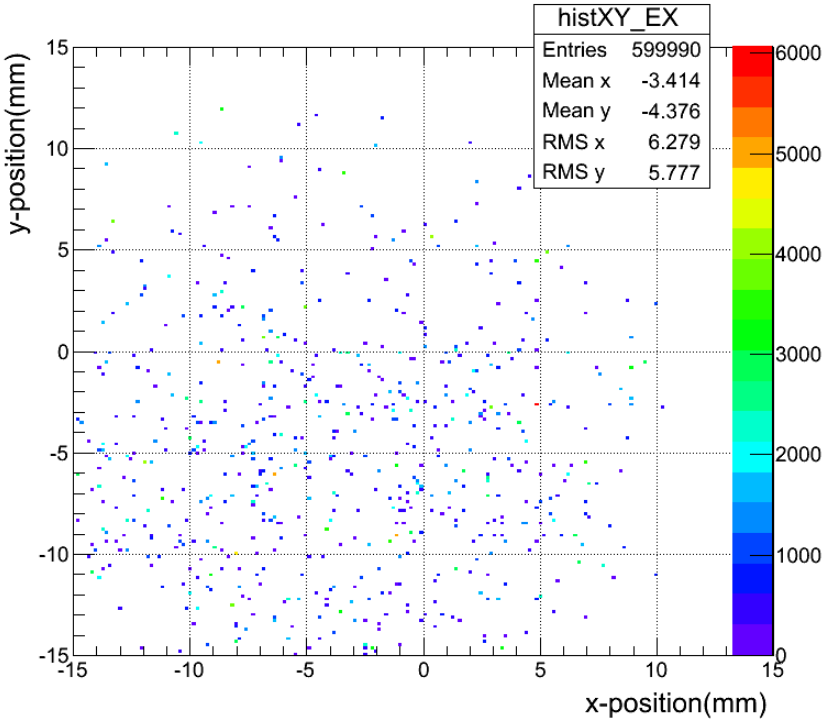
CCD
- **30x 30 mm²**
- **Material: Air**

Pinhole aperture
- **D=6 mm**

Wavelength shift
- **RhD fluorophore** (λ=565 nm)
- **Voxelized-phantom (Tumor)**

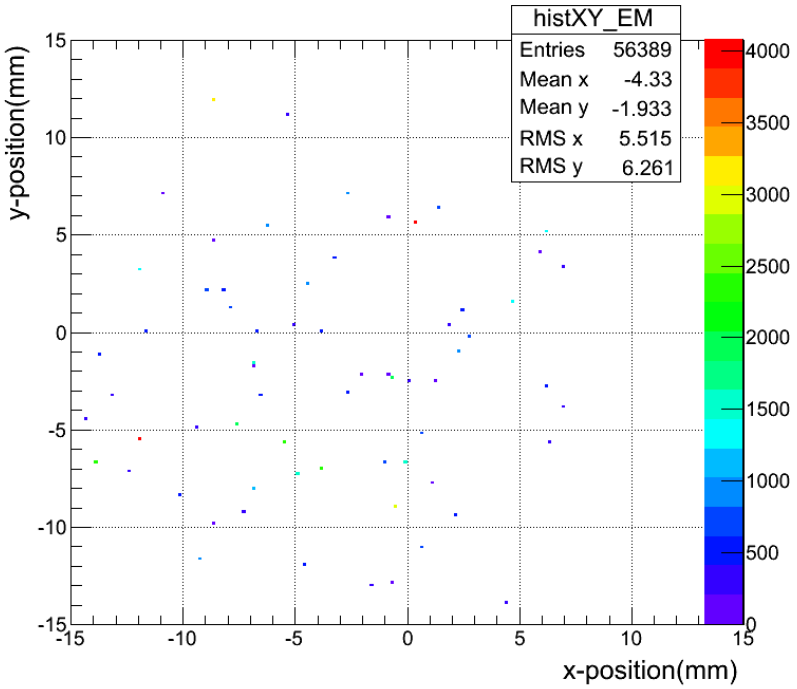
Fluorescence simulation results

Excitation image



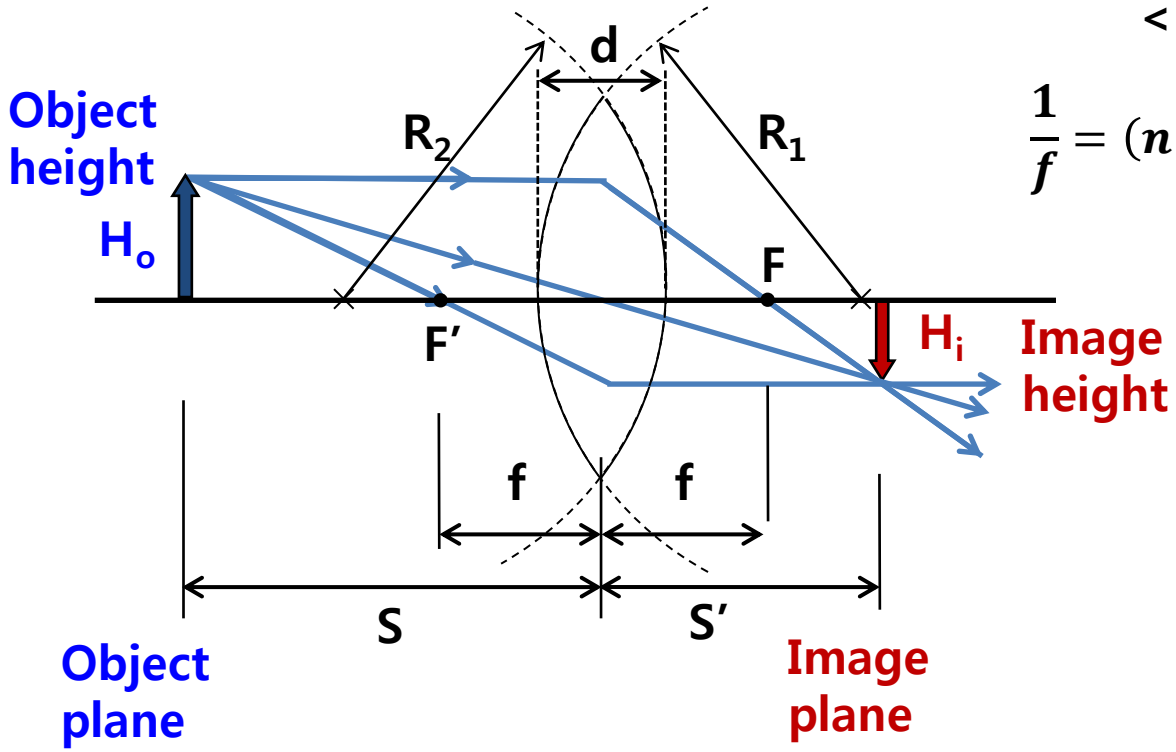
CCD size =30 mm^2

Emission image



GATEv7.1 voxelized source and phantom simulation with a lens

Lensmaker's equation



<Lensmaker's equation>

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right] \quad (1)$$

<Thin lens formula>

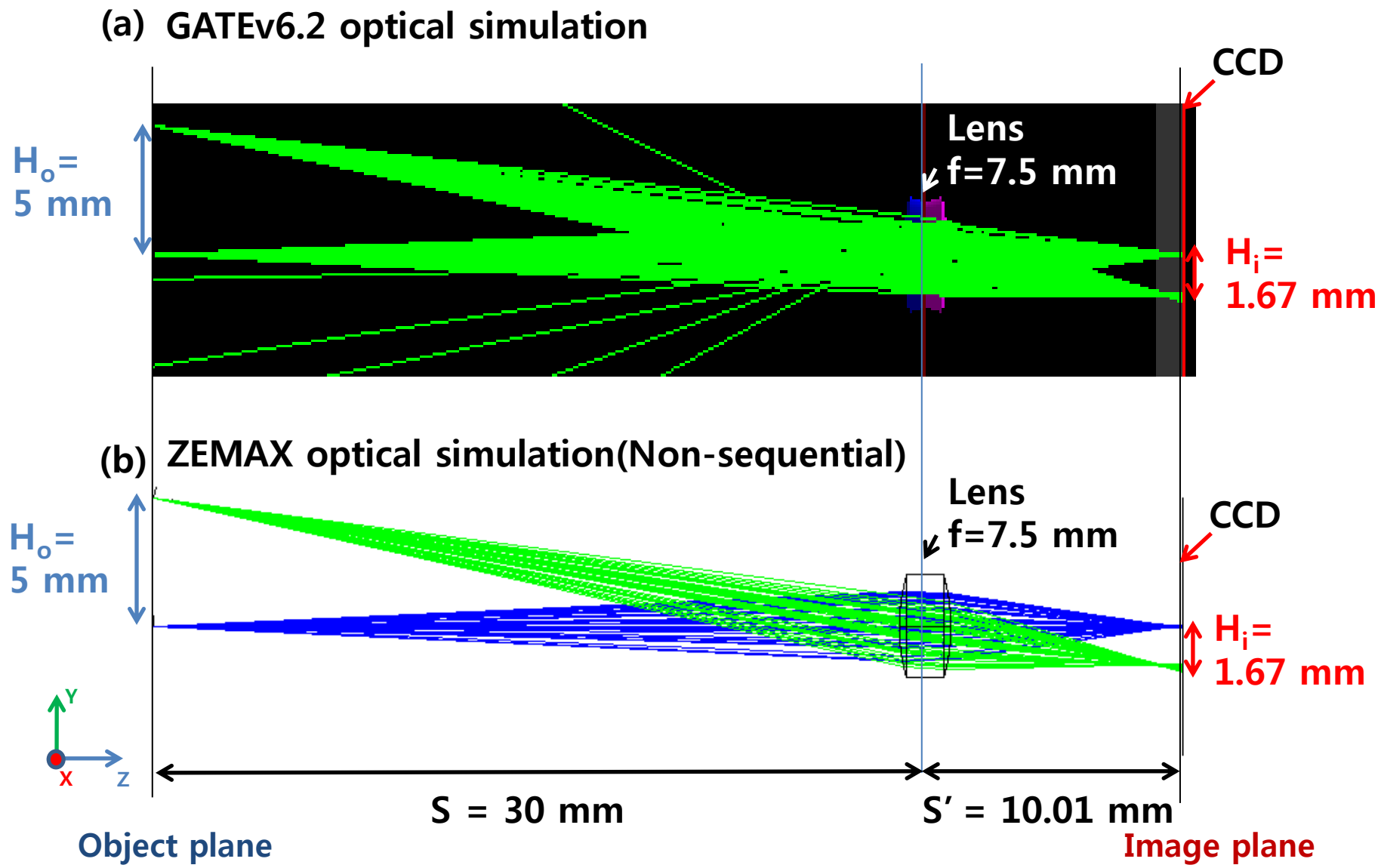
$$\frac{1}{S} + \frac{1}{S'} = \frac{1}{f} \quad (2)$$

$$S' = \frac{S \cdot f}{S - f} \quad (3)$$

$$m = -\frac{S'}{S} \quad (4)$$

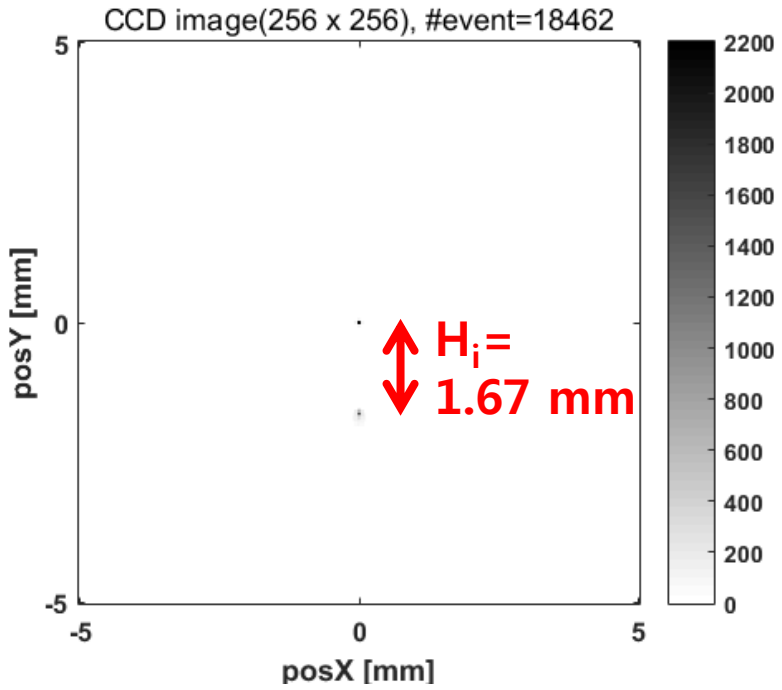
- R1 = +7.3 mm
- R2 = -7.3 mm
- f = 7.5 mm
- m = -0.33

GATEv7.1 vs. ZEMAX(Non-Seq)

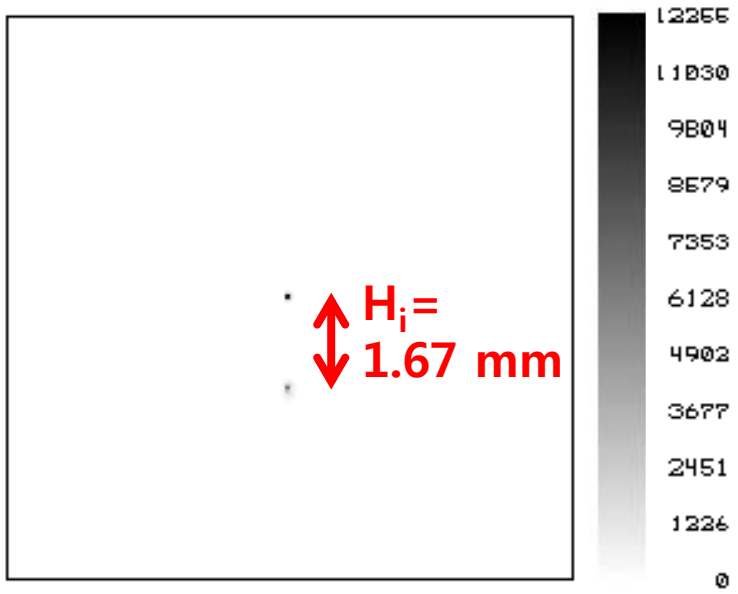


GATEv7.1 vs. ZEMAX

GATE (2D Hits)

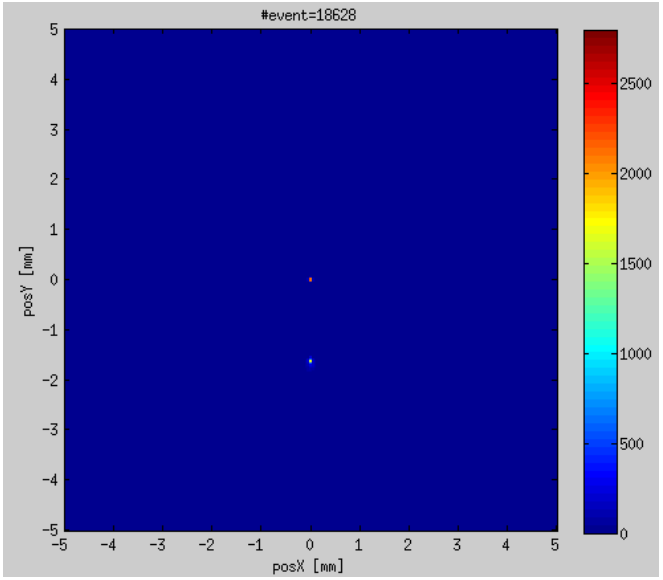


ZEMAX (Detector)

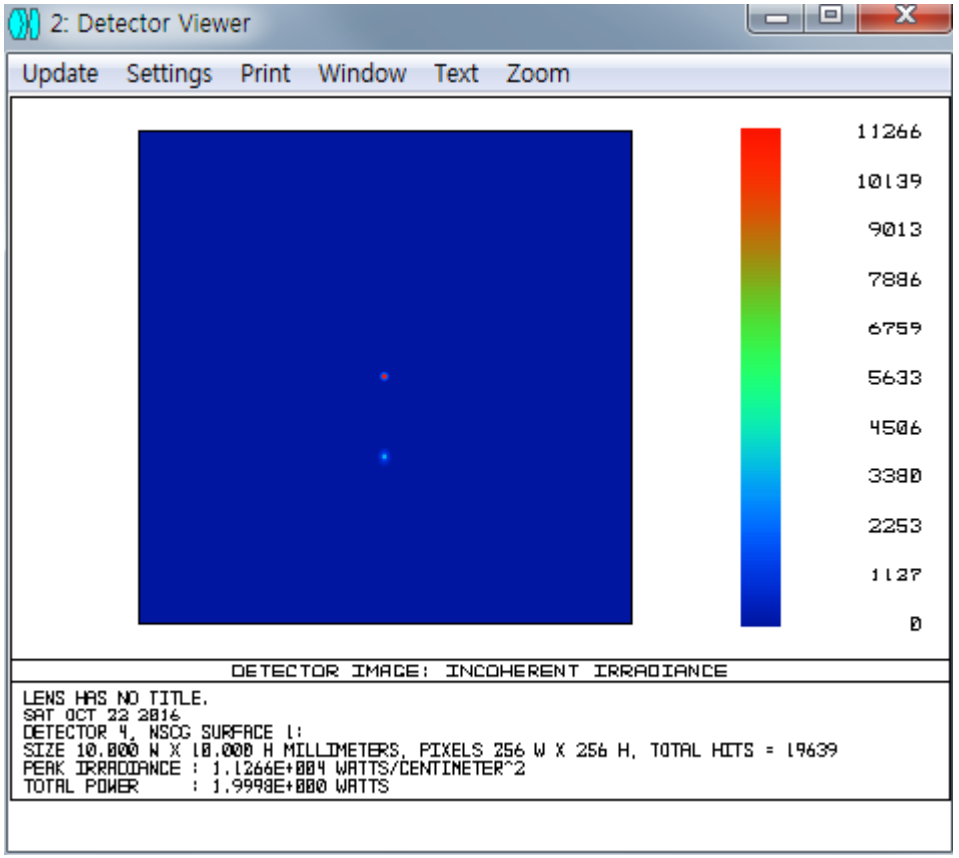


GATEv7.1 vs. ZEMAX

GATE (2D Hit positions)

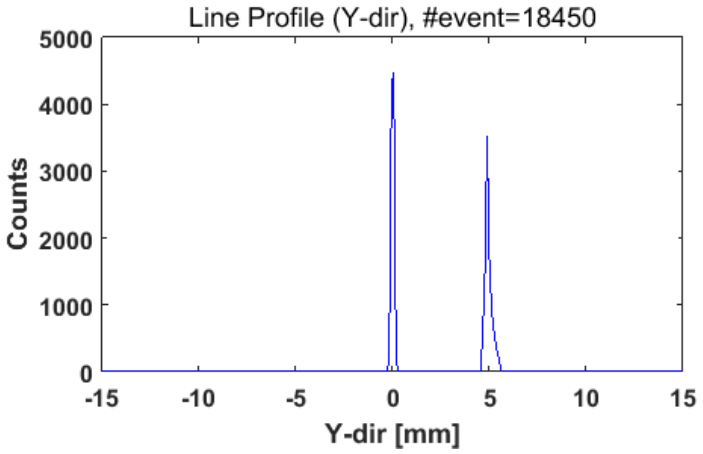


ZEMAX (Detector viewer)

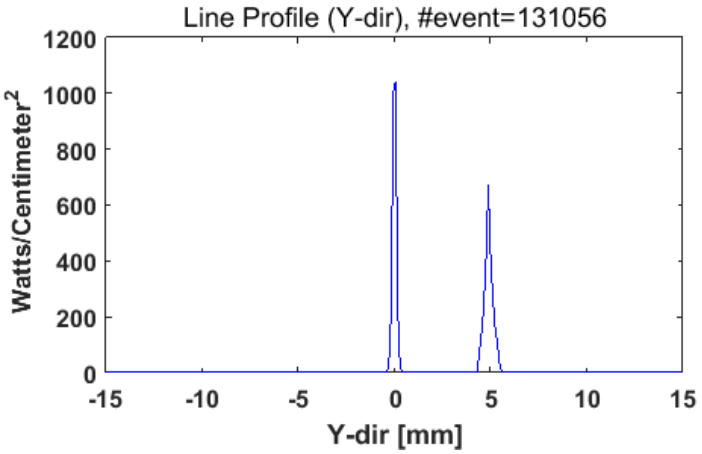


GATEv7.1 vs. ZEMAX

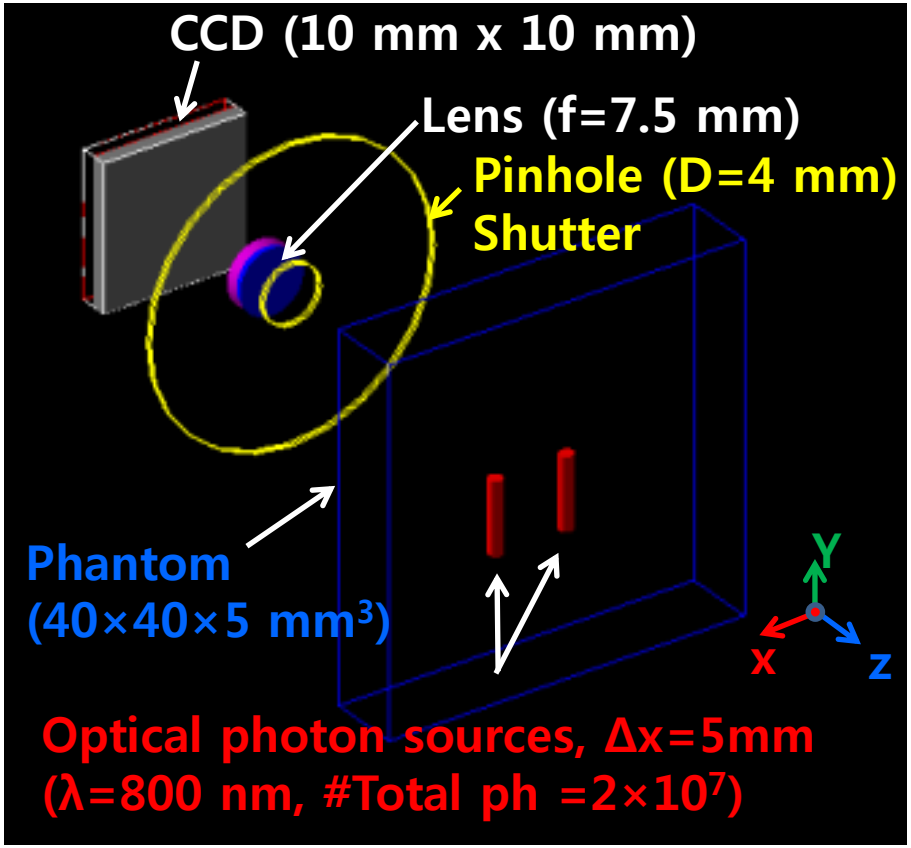
GATE (2D Hit positions)

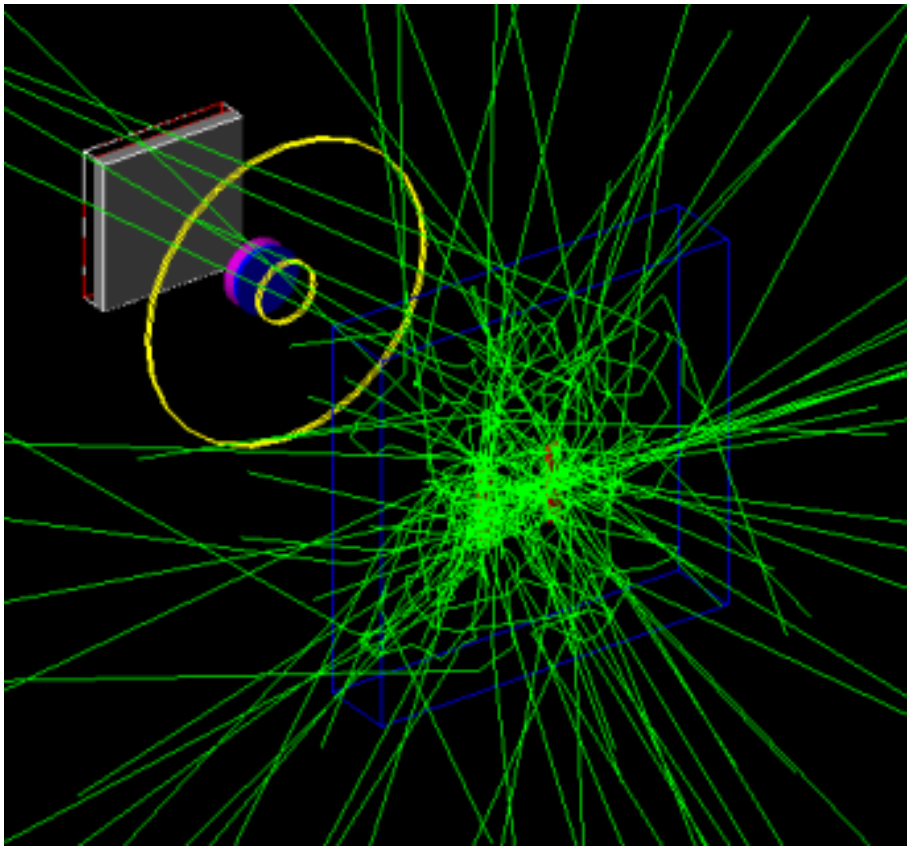


ZEMAX (Detector viewer)

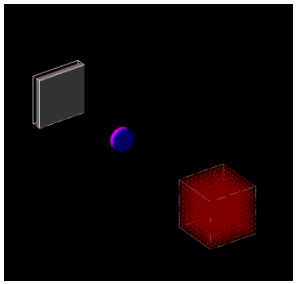
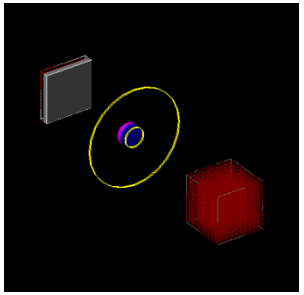
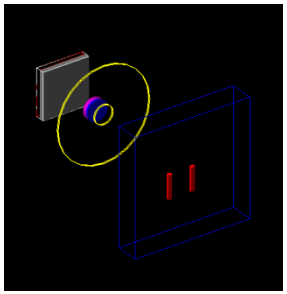
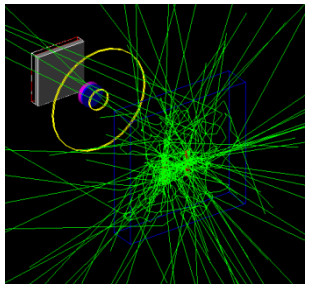
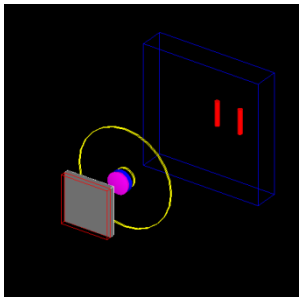
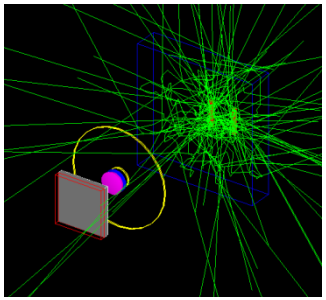
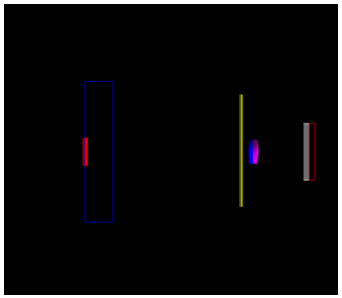
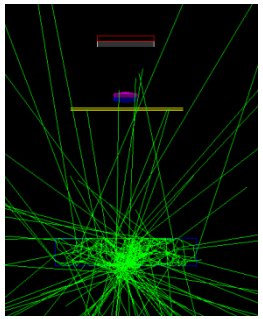


GATEv7.1 optical simulation with lens setup

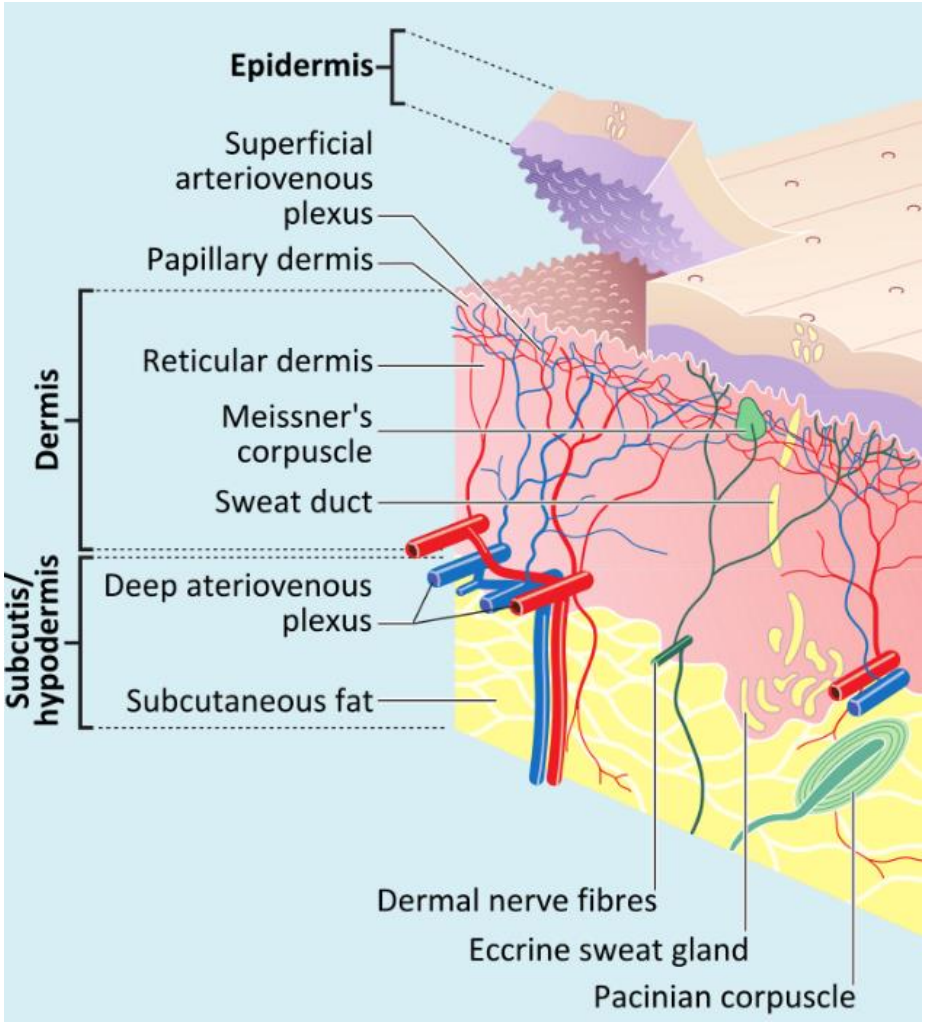




GATEv7.1 simulation screenshots

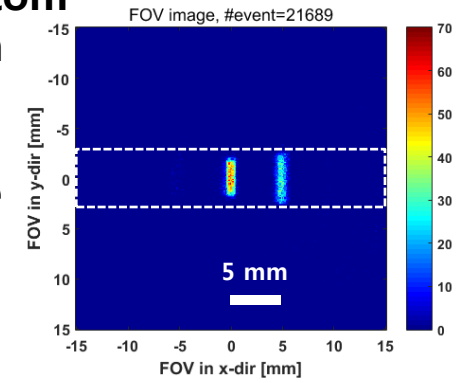
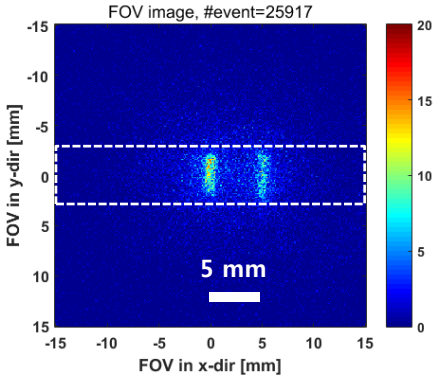
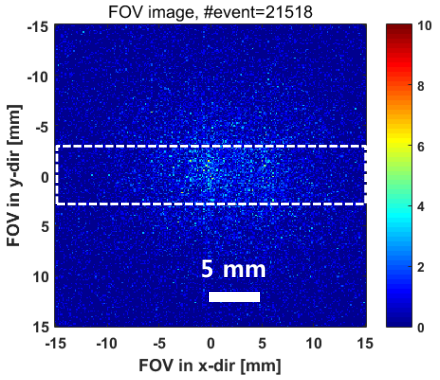
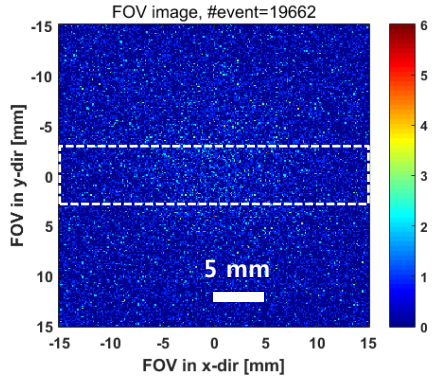
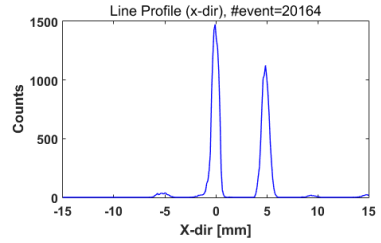
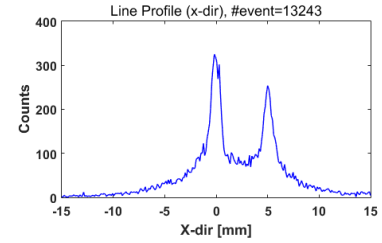
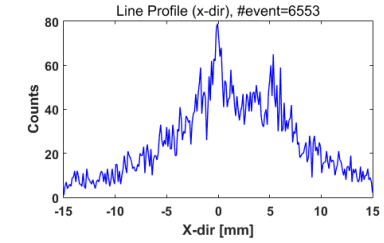
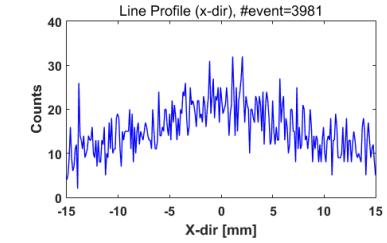









Skin layers



https://en.wikipedia.org/wiki/Skin

Water Phantom

Water phantom depth	0 mm	5 mm	10 mm	15 mm
CCD image				
Line profile				

Refractive index = 1.33
Absorption length = 50 m
Rayleigh scattering length = 10.8 mm

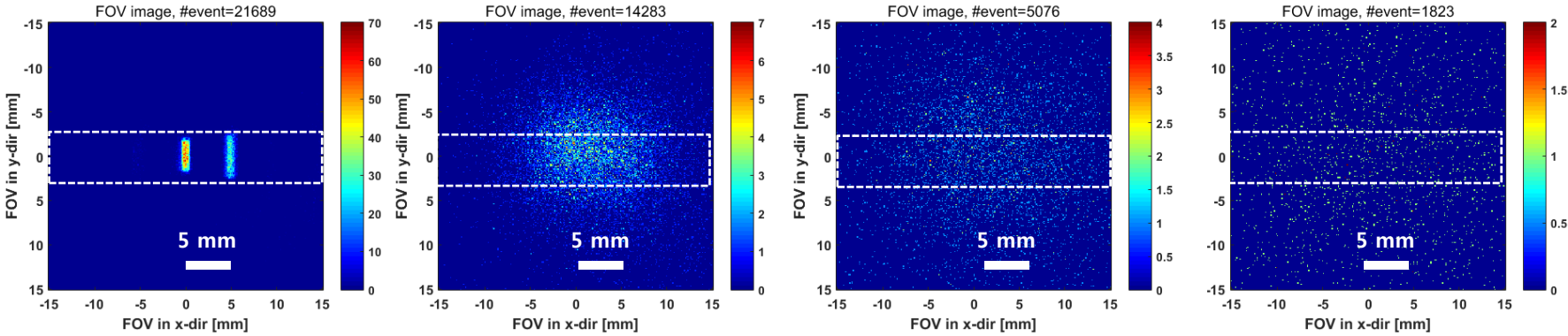
MIEHG_FORWARD = 0.6
MIEHG_BACKWARD = 0.6
MIEG= 2.0 mm

Hypodermis Phantom

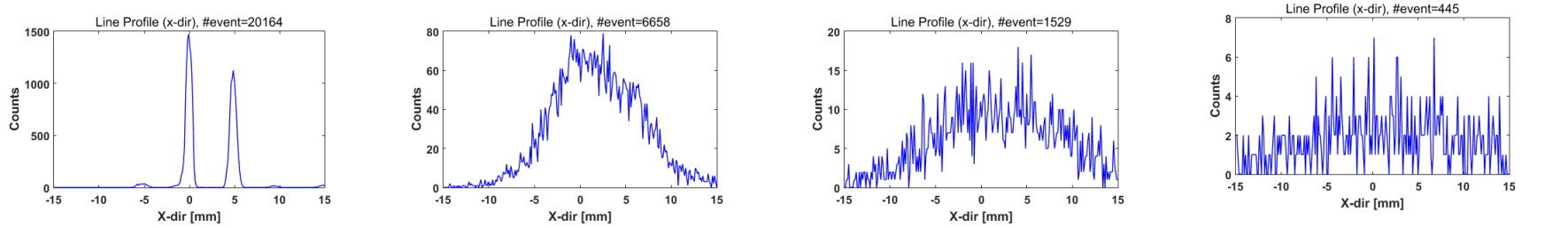
Hypodermis phantom depth

0 mm | 5 mm | 10 mm | 15 mm

CCD image



Line profile



Refractive index = 1.37

Absorption length = 77 mm

Rayleigh scattering length = No

MIEHG_FORWARD = 0.8

MIEHG_BACKWARD = 0.8

MIEG= 0.15873 mm

Epidermis Phantom

Epidermis phantom depth

CCD image

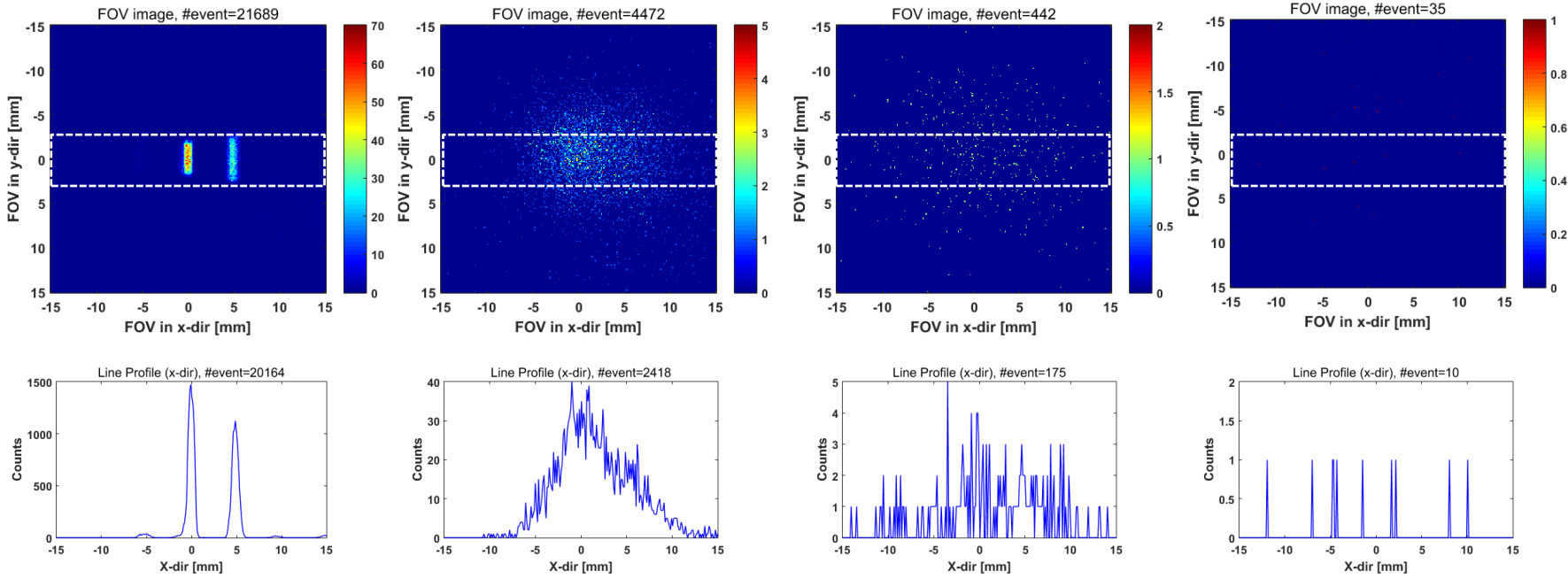
Line profile

0 mm

5 mm

10 mm

15 mm



Refractive index = 1.37

Absorption length = 30 mm

Rayleigh scattering length = No

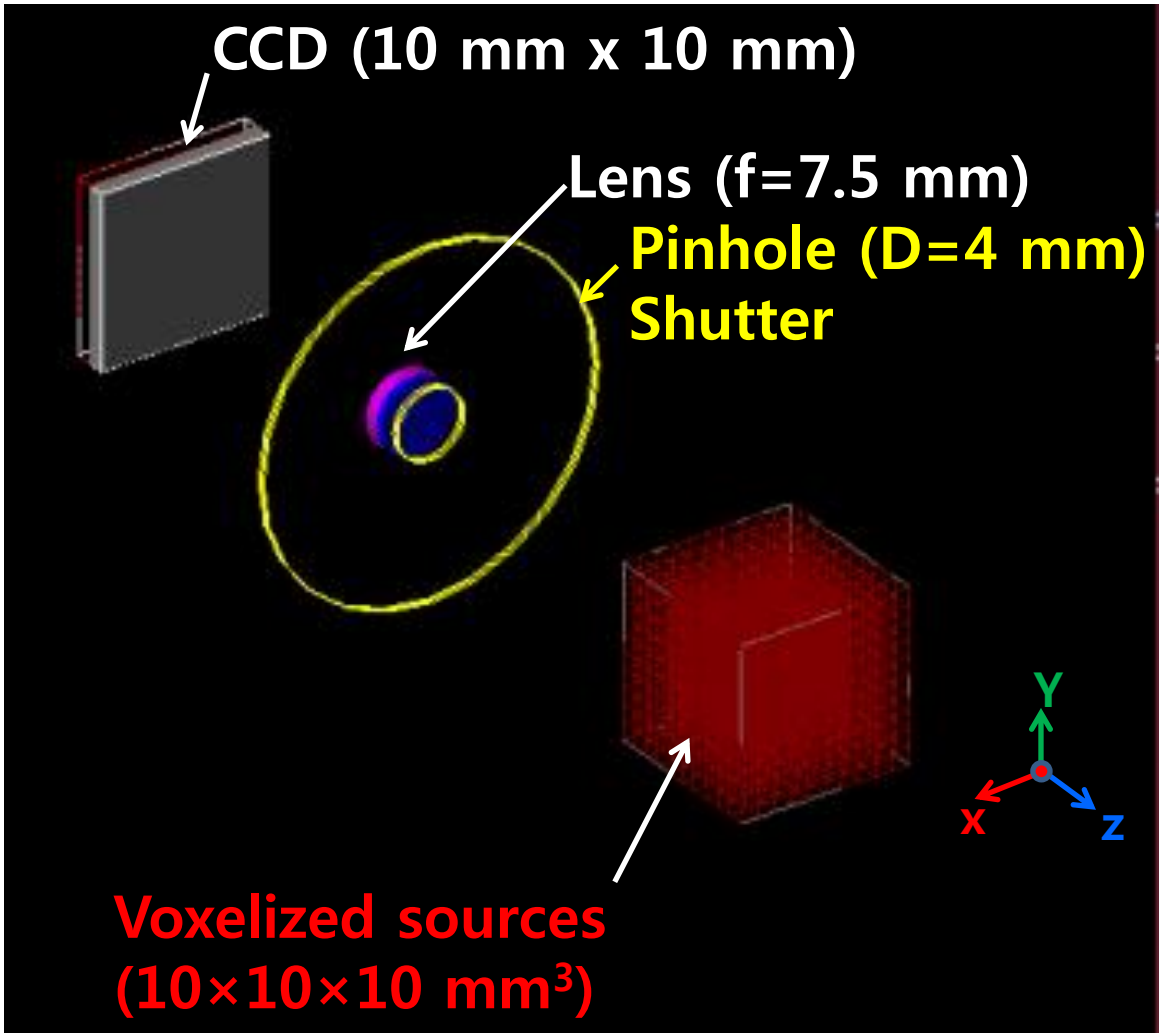
MIEHG_FORWARD = 0.8

MIEHG_BACKWARD = 0.8

MIEG= 0.07326 mm

GATEv7.1 Voxelized phantom optical simulation (4 spots)

GATEv7.1 optical simulation setup



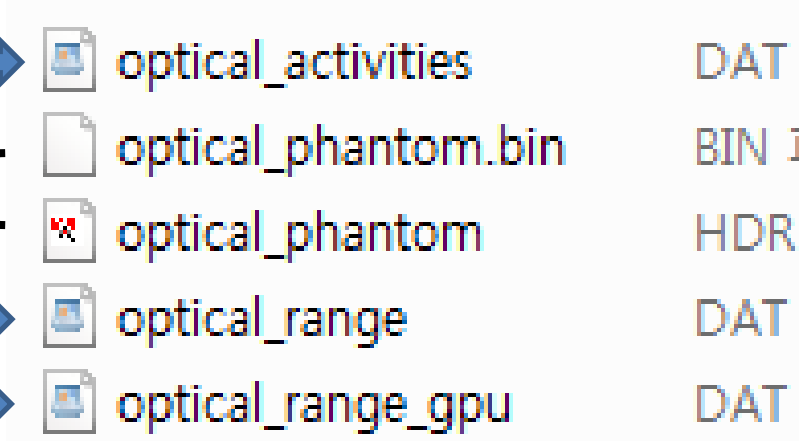
Voxelized source and phantom (Interfile format)

Optical source intensity setting

Voxelized source and phantom (Interfile format)

Optical phantom setting(CPU)

Optical phantom setting(GPU)



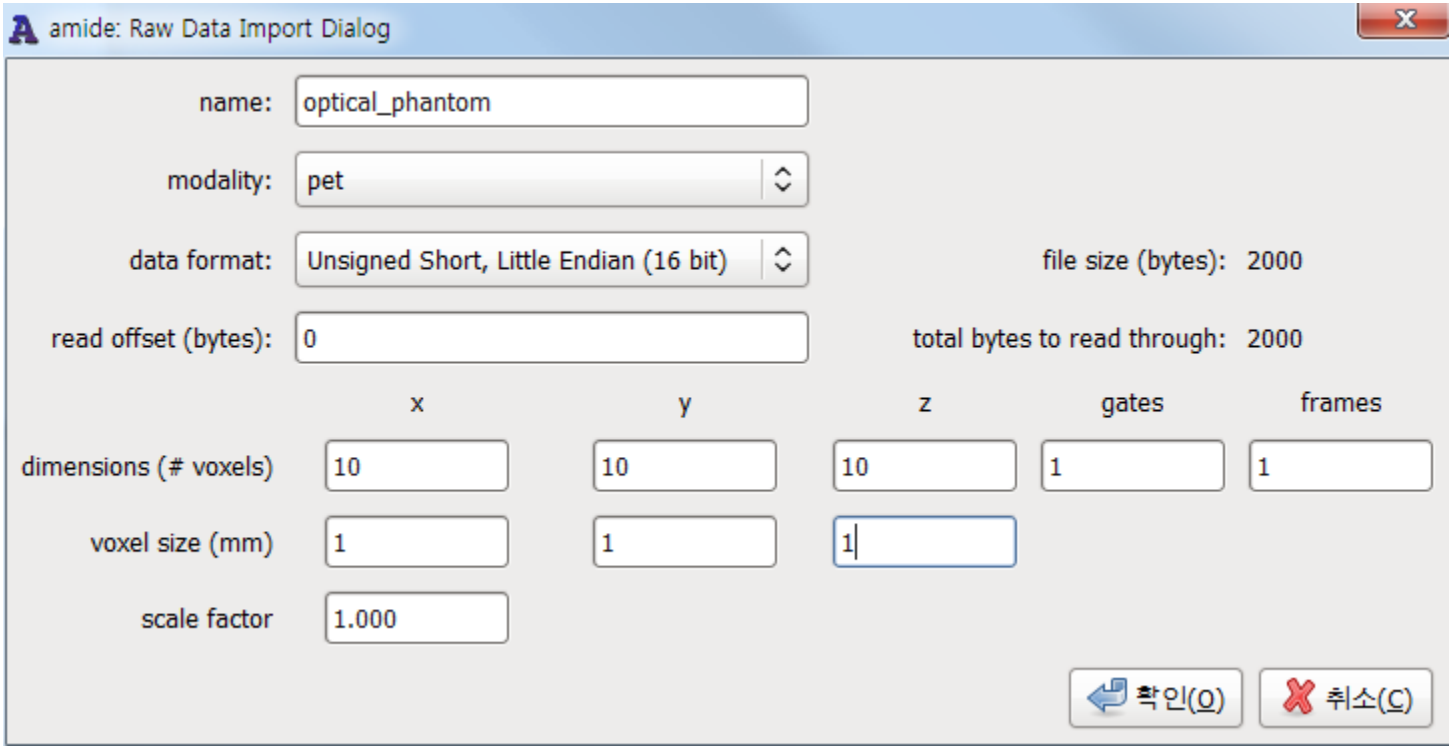
optical_phantom.hdr

- optical_phantom.bin (3D image)
- optical_phantom.hdr (header)

!INTERFILE :=
!name of data file := ./voxelized-source-phantom-4spots/optical_phantom.bin
imagedata byte order := LITTLEENDIAN
!matrix size [1] := 10
!matrix size [2] := 10
!number format := unsigned integer
scaling factor (mm/pixel) [1] := +1.000e+00
scaling factor (mm/pixel) [2] := +1.000e+00
!number of slices := 10
number of reference frame := 0
slice orientation := Transverse
slice thickness (pixels) := +1.0000e+00
centre-centre slice separation (pixels) := +0.500000e+00
filter name := Unknown
filter parameters := Cutoff
method of attenuation correction := measured
scatter corrected := N
oblique reconstruction := N
!END OF INTERFILE :=

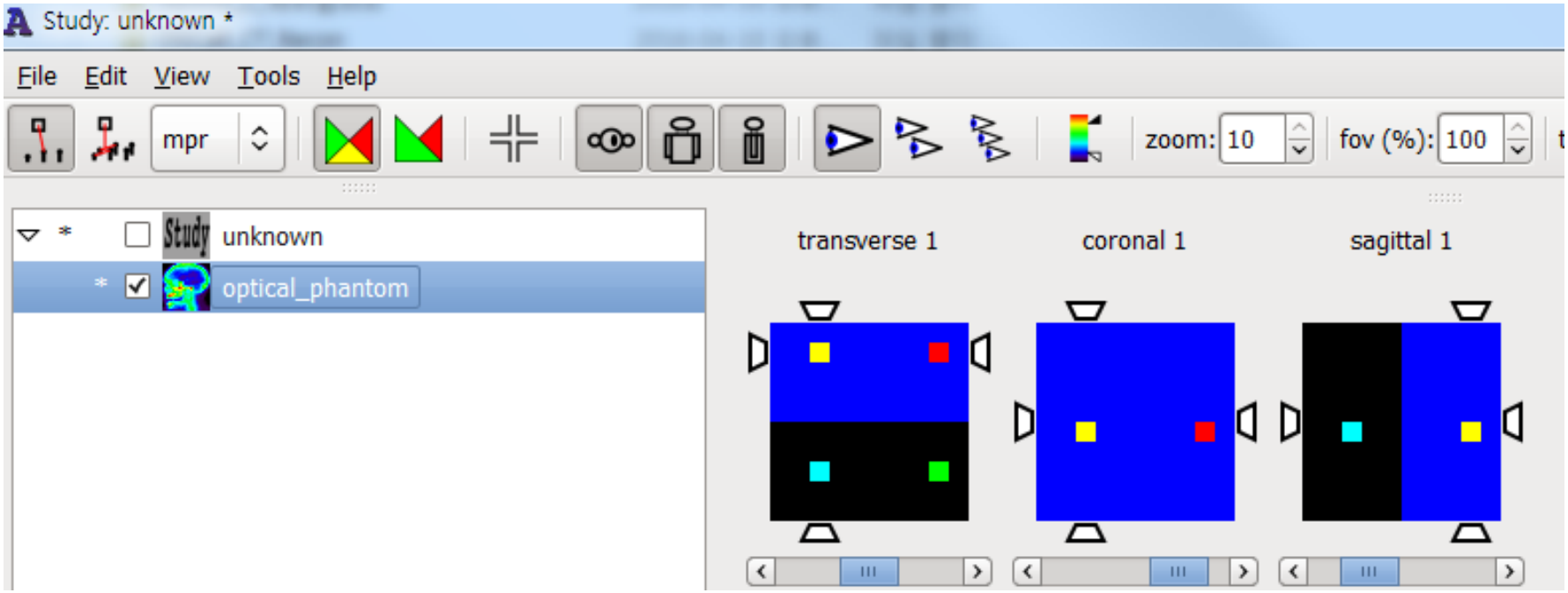
- optical_phantom.bin (3D image)

AMIDE raw data import (Voxelized phantom)



Voxelized source and phantom (Interfile format)

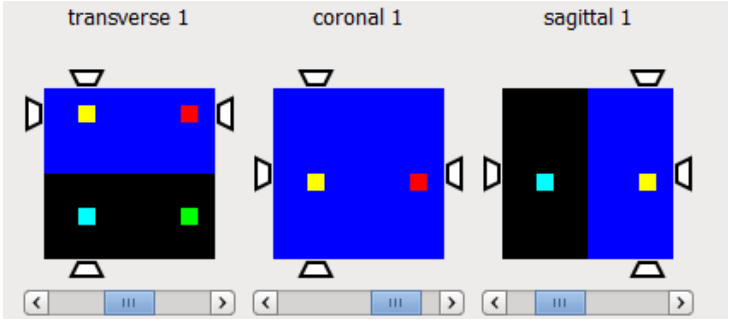
- **optical_phantom.bin (3D image)**
- optical_phantom.hdr (header)



optical_activities.dat
(Voxel intensity to optical activity translator)

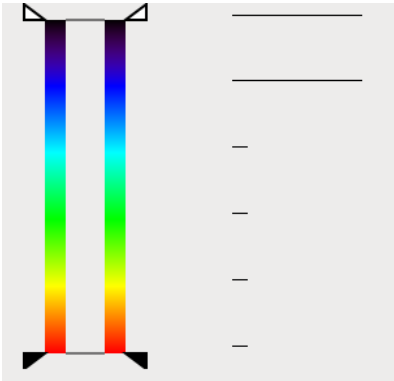
optical_activities.dat

optical_activities DAT 파일



6
0 0 0.0
10 10 0.0
20 20 10.0
30 30 20.0
40 40 10.0
50 50 20.0

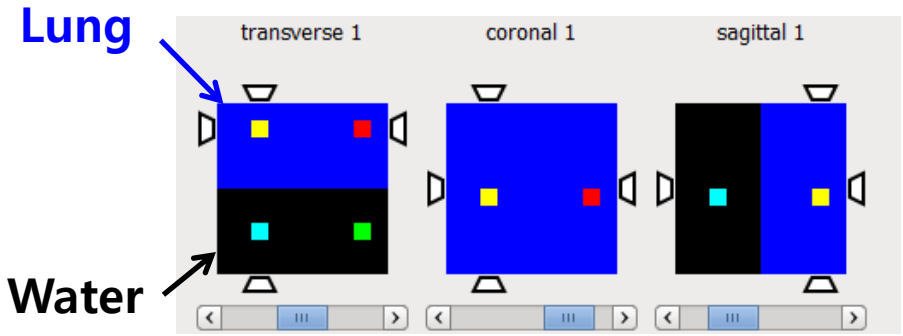
#of_activity_ranges
Pixel_Lower Pixel_Upper Activity[Bq]
Pixel_Lower Pixel_Upper Activity[Bq]
Pixel_Lower Pixel_Upper Activity[Bq]
Pixel_Lower Pixel_Upper Activity[Bq]
Pixel_Lower Pixel_Upper Activity[Bq]
Pixel_Lower Pixel_Upper Activity[Bq]



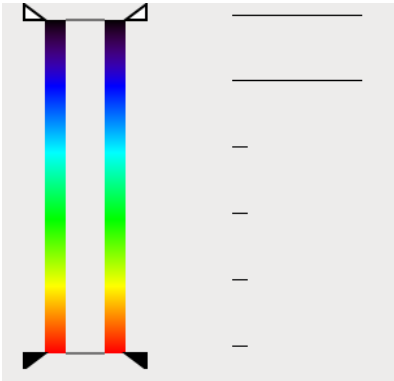
optical_range.dat
(Voxel intensity to optical material translator)

optical_range.dat

optical_range DAT



6 #of_activity_ranges
0 0 Water Pixel_Lower Pixel_Upper Material
10 10 Lung Pixel_Lower Pixel_Upper Material
20 20 Water Pixel_Lower Pixel_Upper Material
30 30 Water Pixel_Lower Pixel_Upper Material
40 40 Lung Pixel_Lower Pixel_Upper Material
50 50 Lung Pixel_Lower Pixel_Upper Material



Materials.xml

Water

```
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    <propertiestable>
<!--      <propertyvector name="ABSLENGTH" unit="m" energyunit="eV">
    <ve energy="1.0" value="50"/>
    <ve energy="1.97" value="50"/>
    <ve energy="2.34" value="50"/>
    <ve energy="4.0" value="50"/>
      </propertyvector>-->
     <propertyvector name="RINDEX" energyunit="eV">
    <ve energy="1.0" value="1.33"/>
    <ve energy="5.0" value="1.33"/>
    <ve energy="6.0" value="1.33"/>
    <ve energy="7.0" value="1.33"/>
      </propertyvector>
<property name="MIEHG_FORWARD" value="0.6" />
      <property name="MIEHG_BACKWARD" value="0.6" />
      <property name="MIEHG_FORWARD_RATIO" value="1.0" />
      <propertyvector name="MIEHG" unit="mm" energyunit="eV">
              <ve energy="1.0" value="2.3"/>
              <ve energy="5.0" value="1.3"/>
              <ve energy="6.0" value="3.2"/>
              <ve energy="7.0" value="6.7"/>
      </propertyvector>
    </propertiestable>
  </material>
```

Materials.xml

Lung

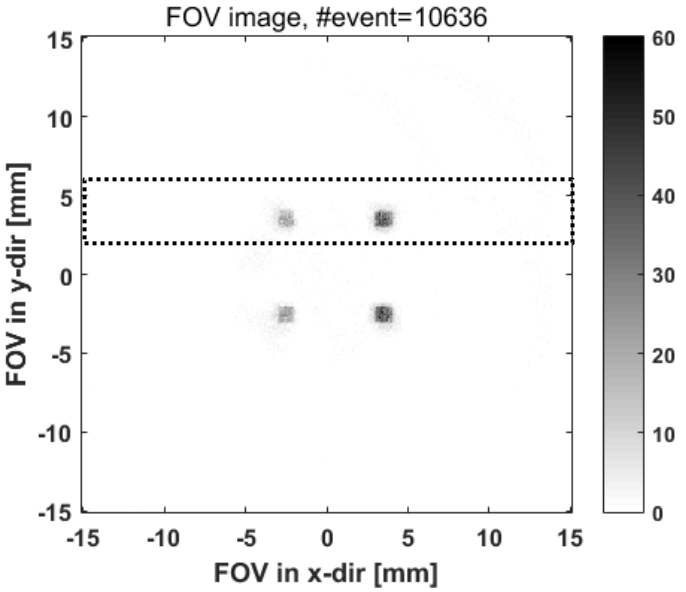
```
<material name="Lung">
    <propertiestable>
     <propertyvector name="RINDEX" energyunit="eV">
    <ve energy="5.0" value="1.4"/>
    <ve energy="6.0" value="1.4"/>
    <ve energy="7.0" value="1.4"/>
      </propertyvector>
  <property name="MIEHG_FORWARD" value="0.6" />
      <property name="MIEHG_BACKWARD" value="0.6" />
      <property name="MIEHG_FORWARD_RATIO" value="1.0" />
      <propertyvector name="MIEHG" unit="mm" energyunit="eV">
        <ve energy="5.0" value="1.3"/>
        <ve energy="6.0" value="1.2"/>
        <ve energy="7.0" value="1.7"/>
      </propertyvector>
   </propertiestable>
  </material>
```

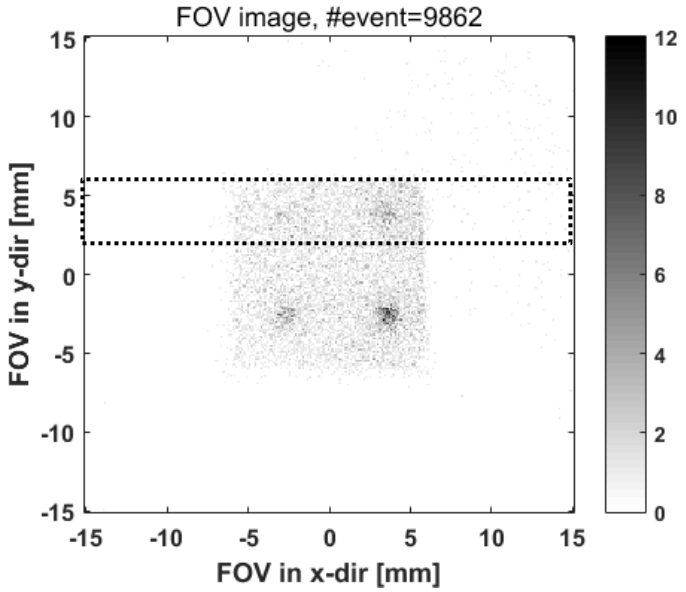
Effect of voxelized phantom on voxelized source image

- Voxelized source
- No Voxelized phantom

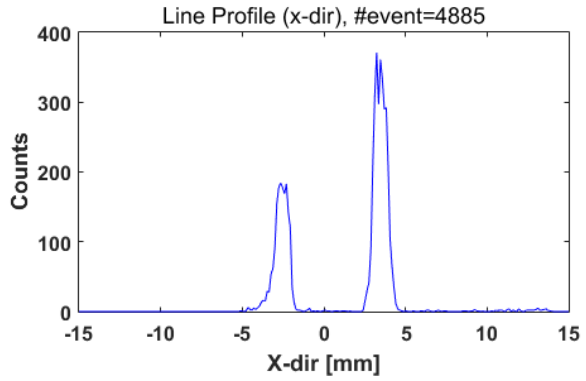
- Voxelized source
- Voxelized phantom

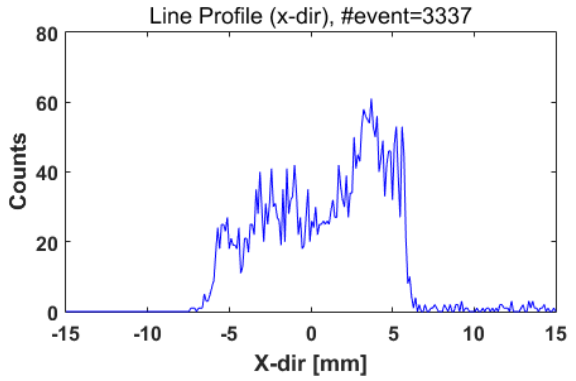
CCD image





Line profile

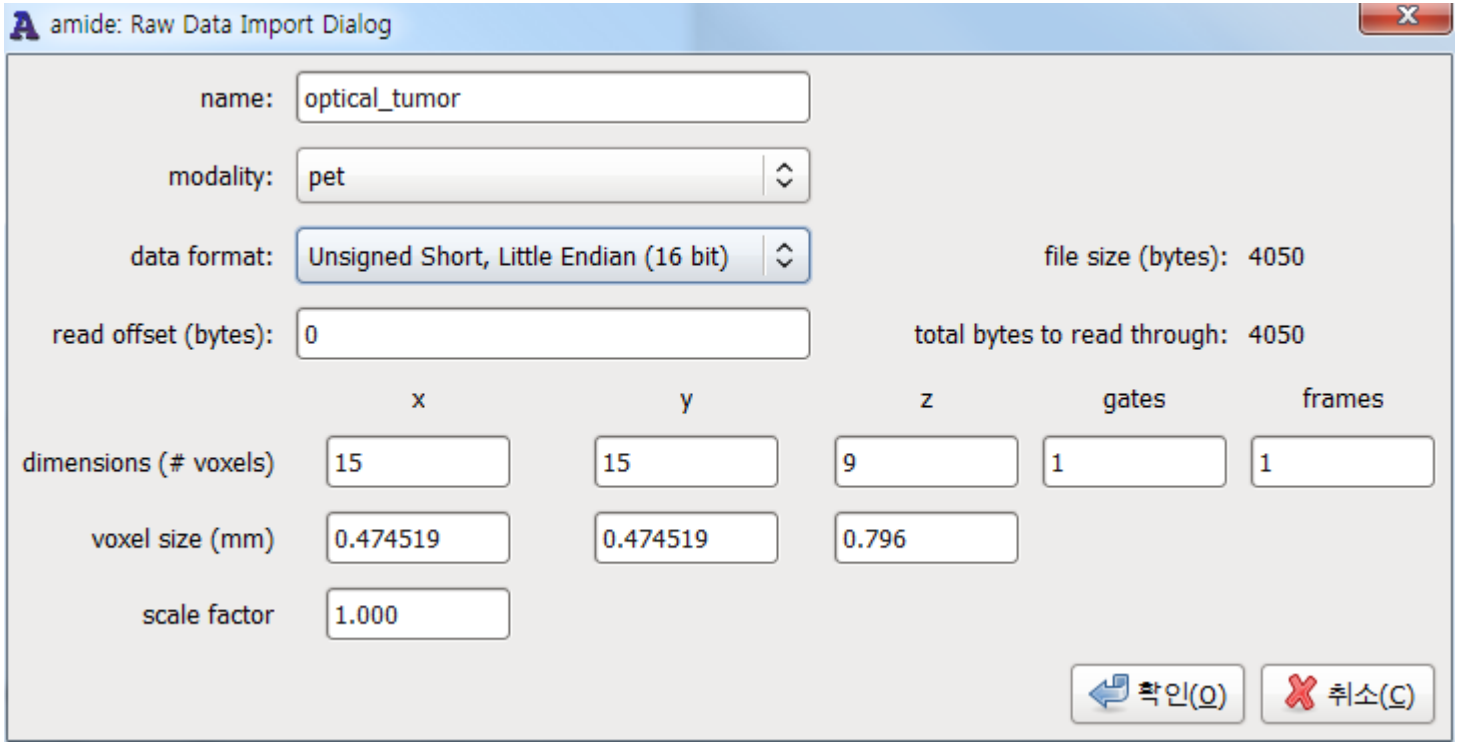




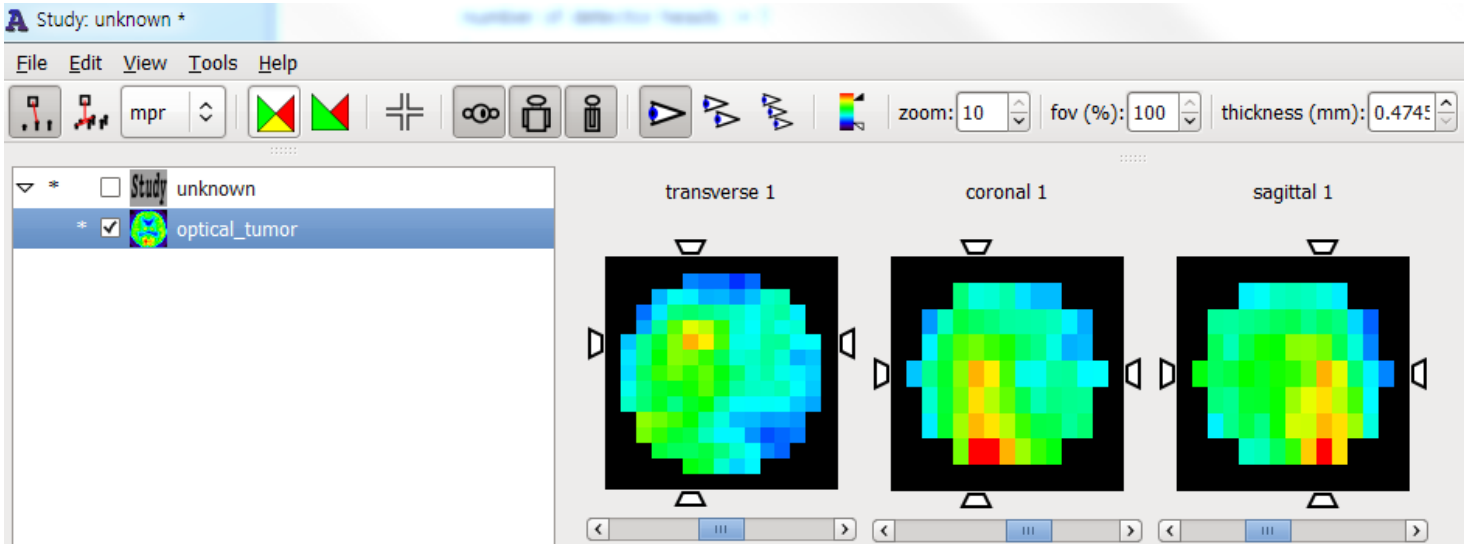
GATEv7.1 Voxelized phantom optical simulation (Tumor)

- optical_tumor.i33 (3D image)

AMIDE raw data import (Voxelized tumor)

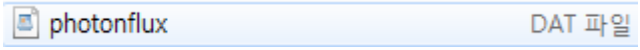


Optical tumor voxelized phantom (Optical_tumor.bin)




```
/gate/source/addSource opt_tum voxel
/gate/source/opt_tum/reader/insert interfile
/gate/source/opt_tum/interfileReader/translator/insert range
/gate/source/opt_tum/interfileReader/rangeTranslator/readTable ./voxelized-source-phantom/photonflux.dat
/gate/source/opt_tum/interfileReader/rangeTranslator/describe 1
/gate/source/opt_tum/interfileReader/readFile ./voxelized-source-phantom/optical_tumor.h33
#/gate/source/opt_tum/setPosition    -6.559 -5.559 -88.0 mm
/gate/source/opt_tum/setPosition    -5 -5 -5 mm
/gate/source/opt_tum/gps/particle opticalphoton
/gate/source/opt_tum/gps/energytype Mono
/gate/source/opt_tum/gps/monoenergy 1.87 eV
/gate/source/opt_tum/gps/direction              0. 0. 1.
/gate/source/opt_tum/gps/polarization           1 0 0
/gate/source/opt_tum/dump 1
```

rangeTranslator

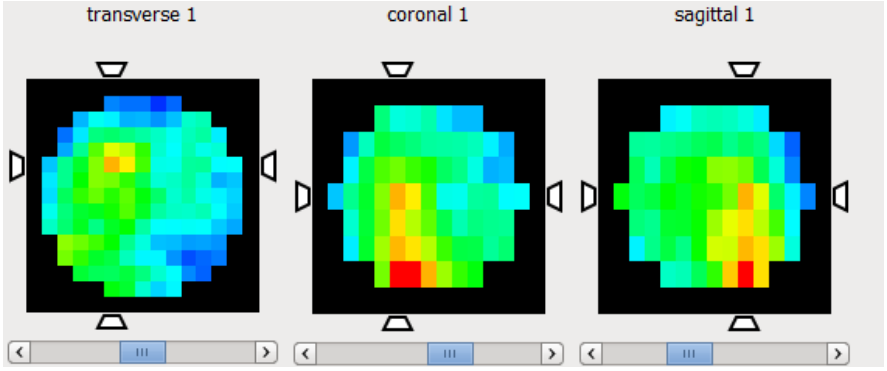


Voxelized-source image data

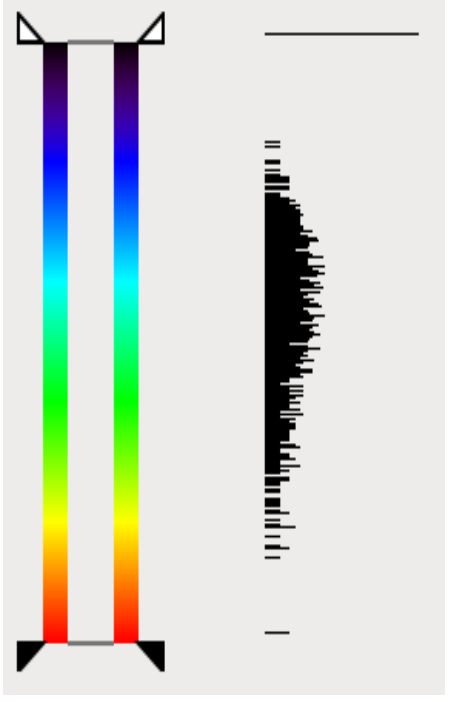
photonflux.dat
(Voxel intensity to optical activity translator)

photonflux.dat

photonflux DAT



8		#of_activity_ranges
0 0 0		Pixel_Lower Pixel_Upper Activity[Bq]
1 20 0		Pixel_Lower Pixel_Upper Activity[Bq]
21 50 0	⟷	Pixel_Lower Pixel_Upper Activity[Bq]
51 63 0		Pixel_Lower Pixel_Upper Activity[Bq]
64 102 600		Pixel_Lower Pixel_Upper Activity[Bq]
103 148		Pixel_Lower Pixel_Upper Activity[Bq]
1200		Pixel_Lower Pixel_Upper Activity[Bq]
149 200		Pixel_Lower Pixel_Upper Activity[Bq]
1800		Pixel_Lower Pixel_Upper Activity[Bq]
201 256		Pixel_Lower Pixel_Upper Activity[Bq]
2560		Pixel_Lower Pixel_Upper Activity[Bq]



optical_tumor.h33 (Interfile header)

```
!INTERFILE :=
!imaging modality := nucmed
!originating system := greetings
!version of keys := 3.3
date of keys := 1996:09:24
conversion program := (X)MedCon
program author := Erik Nolf
program version := 0.7.4
program date := 2002:02:18
;
!GENERAL DATA :=
!data offset in bytes := 0
!name of data file := ./voxelized-source-phantom-tumor/optical_tumor.i33
patient name := hf
!patient ID := 271097
patient dob := 0000:00:00
patient sex := Unknown
!study ID := brain
exam type := pet    study
data compression := none
data encode := none
;
```

optical_tumor.h33 (Interfile header)

```
!GENERAL IMAGE DATA :=
!type of data := Tomographic
!total number of images := 9
study date := 1997:11:28
study time := 00:00:00
imagedata byte order := LITTLEENDIAN
;
number of energy windows := 1
;
energy window [1] :=
energy window lower level [1] :=
energy window upper level [1] :=
flood corrected := N
decay corrected := N
;
!SPECT STUDY (general) :=
number of detector heads := 1
;
!number of images/energy window := 9
!process status := Reconstructed
!matrix size [1] := 15
!matrix size [2] := 15
!number format := unsigned integer
!number of bytes per pixel := 2
```

optical_tumor.h33 (Interfile header)

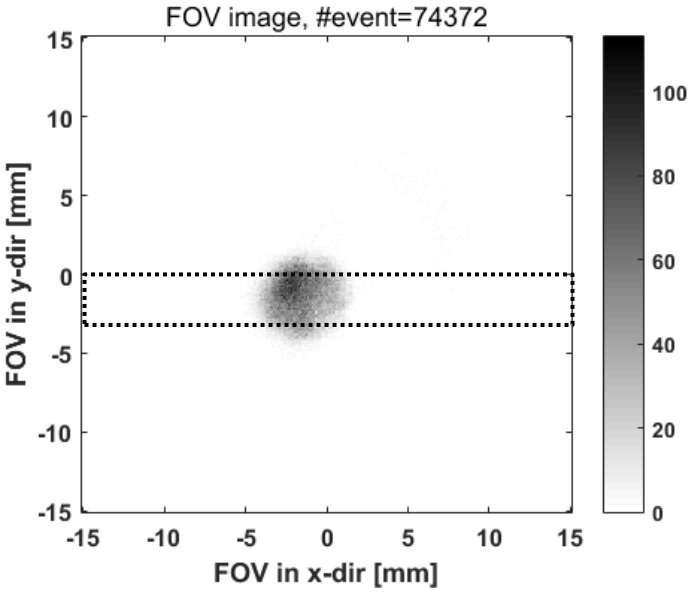
scaling factor (mm/pixel) [1] := +0.474519e+00
scaling factor (mm/pixel) [2] := +0.474519e+00
!number of projections := 9
!extent of rotation :=
!time per projection (sec) := 0
study duration (sec) := 0
!maximum pixel count := +2.000000e+02
patient orientation := head_in
patient rotation := supine
;
!SPECT STUDY (reconstructed data) :=
method of reconstruction := Unknown
!number of slices := 9
number of reference frame := 0
slice orientation := Transverse
slice thickness (pixels) := +0.796e+00
centre-centre slice separation (pixels) := +0.796e+00
filter name := Unknown
filter parameters := Cutoff
method of attenuation correction := measured
scatter corrected := N
oblique reconstruction := N
!END OF INTERFILE :=

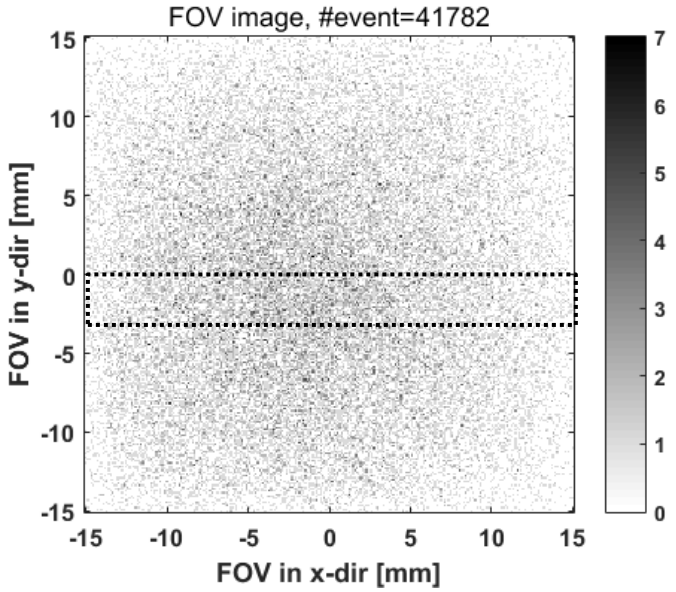
Effect of epidermis, hypodermis and water phantom on voxelized source image

- Voxelized source(Tumor)
- No phantom

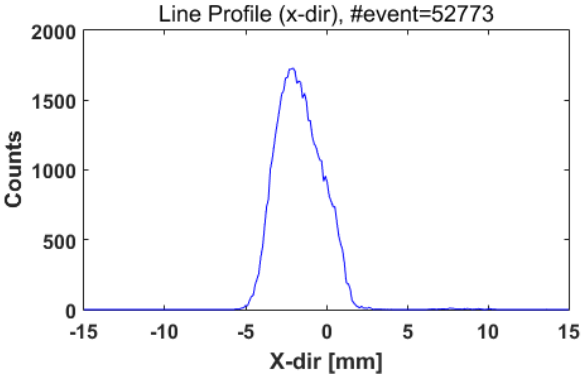
- Voxelized source(Tumor)
- Epidermis, Hypodermis WaterPhantom

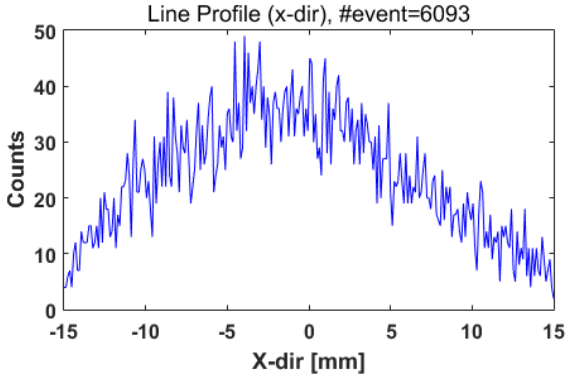
CCD image





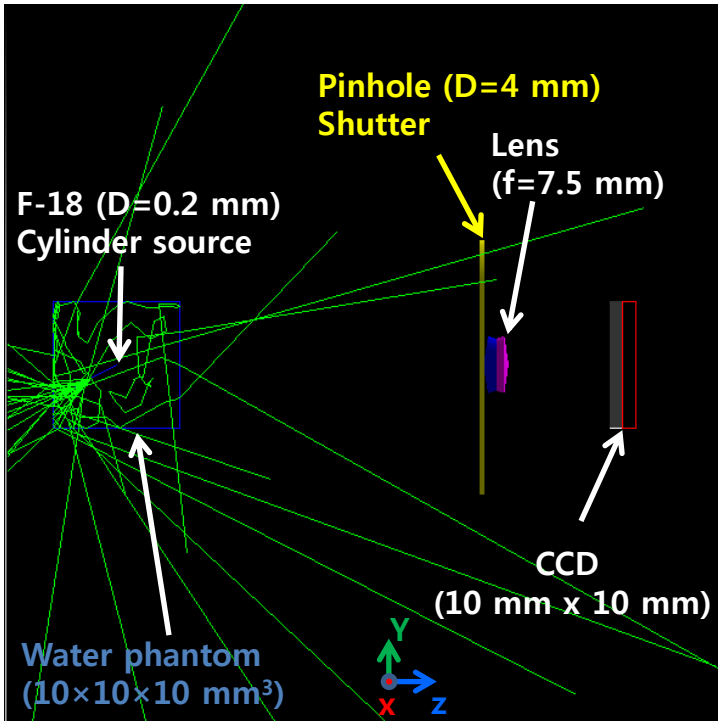
Line profile

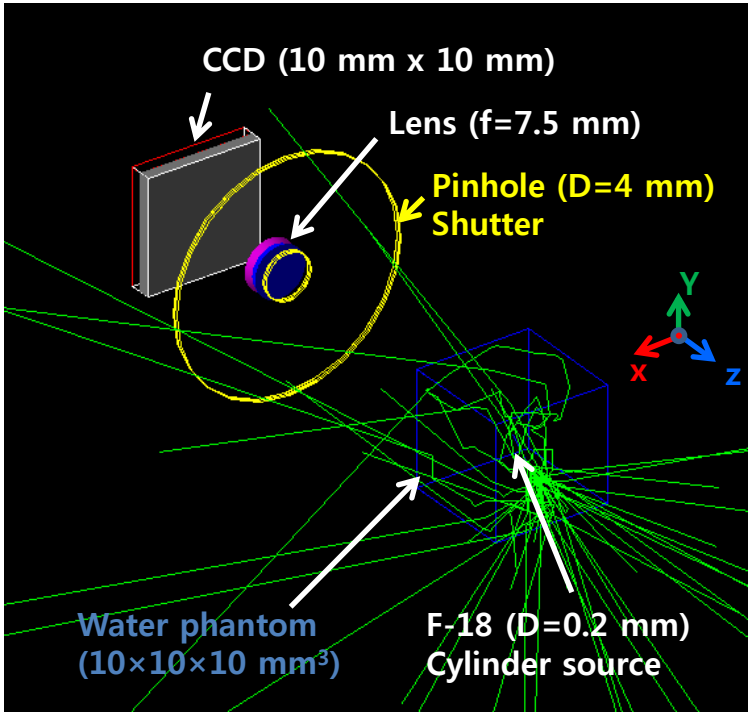




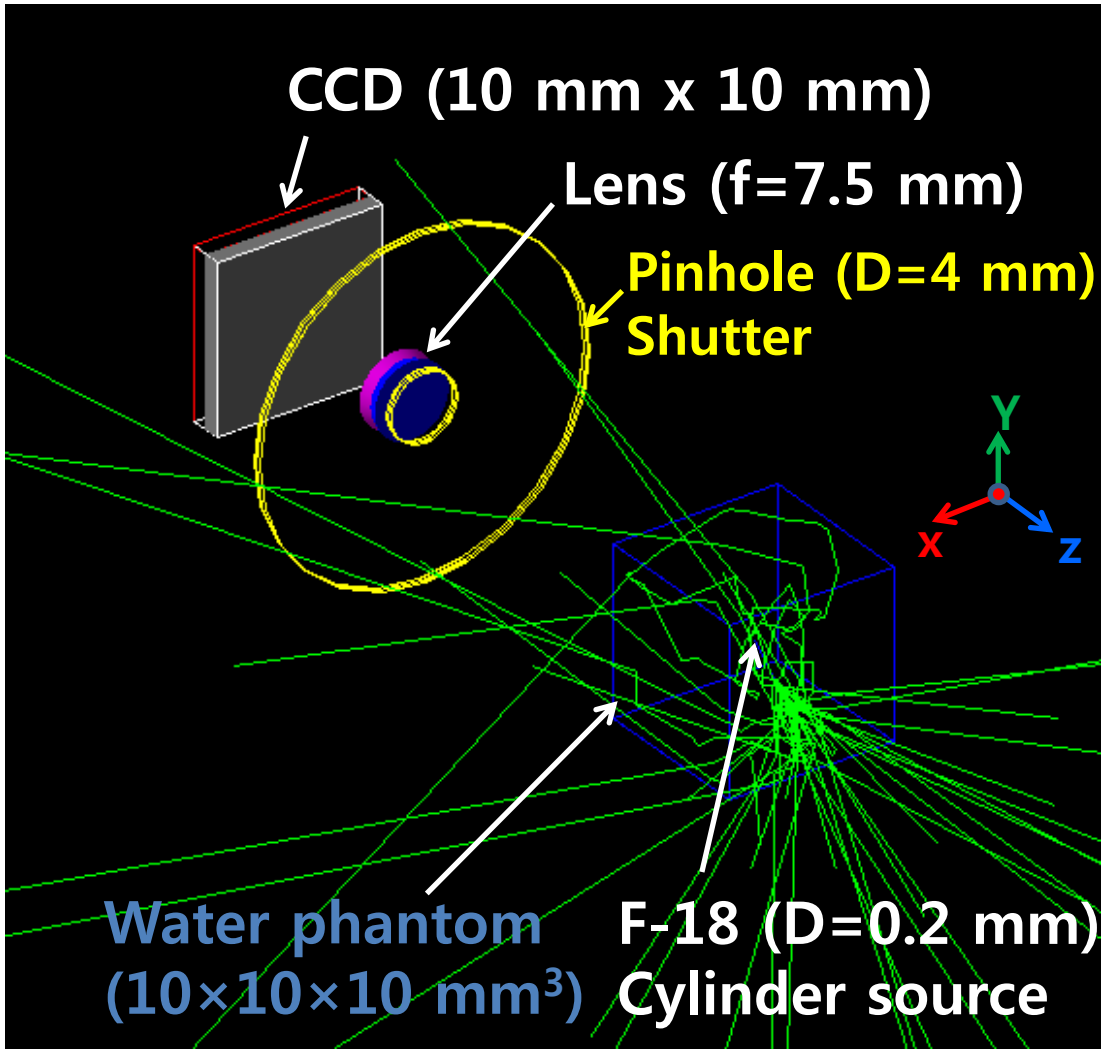
Cerenkov imaging simulation (GATEv6.2)

Cerenkov simulation (GATEv6.2)





GATEv6.2 Cerenkov simulation setup

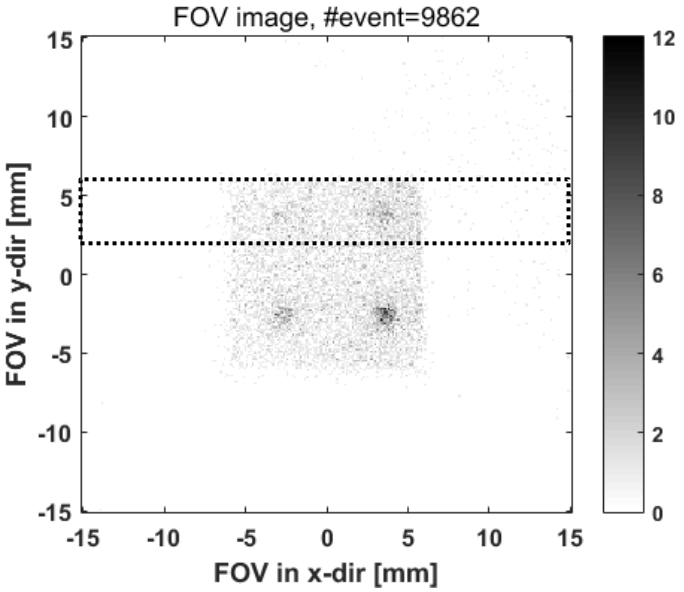


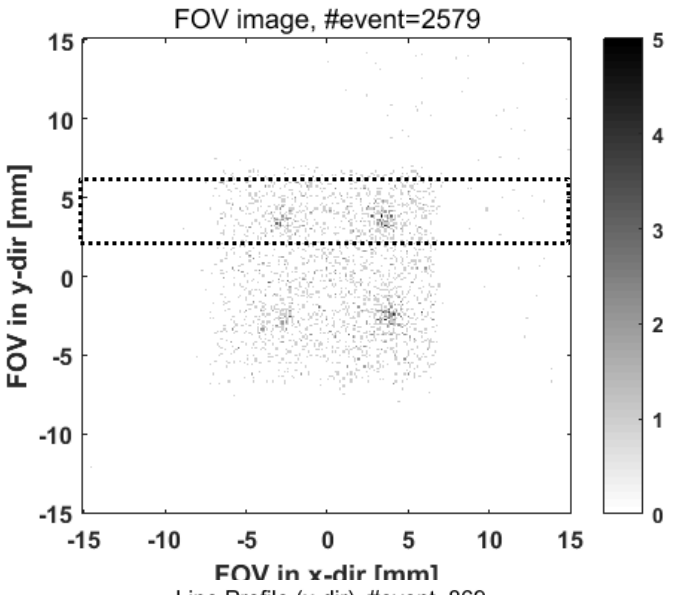
Bioluminescence vs. Cerenkov

- Voxelized source (Optical)
- Voxelized phantom

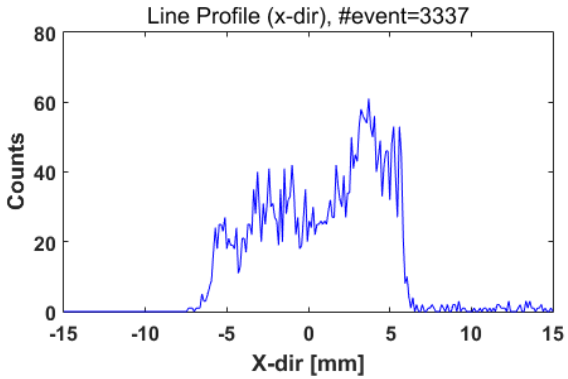
- Voxelized source (F-18)
- Voxelized phantom

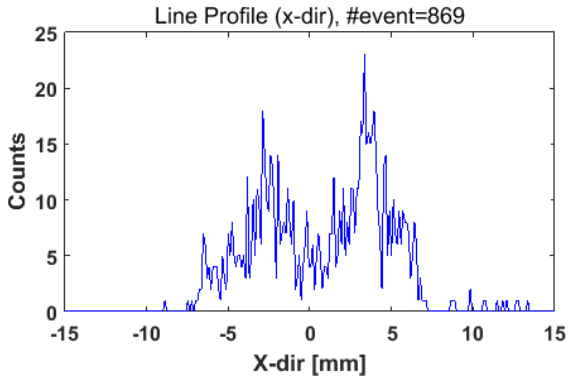
CCD image



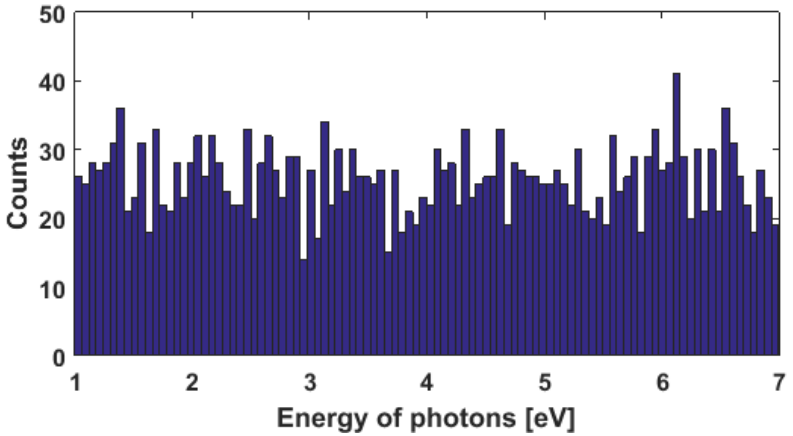


Line profile

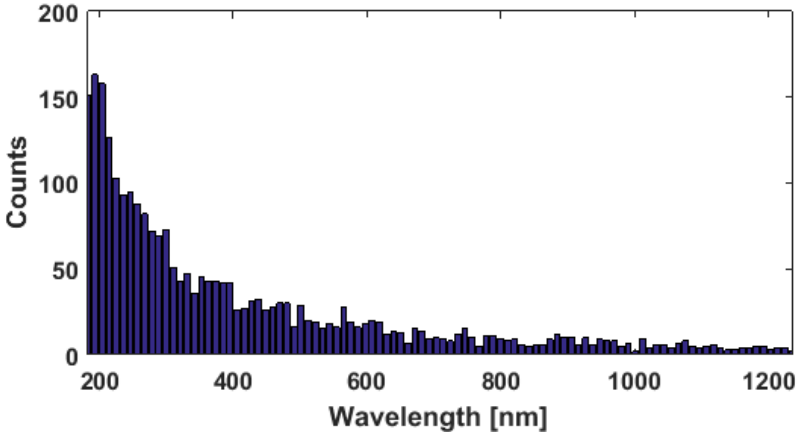




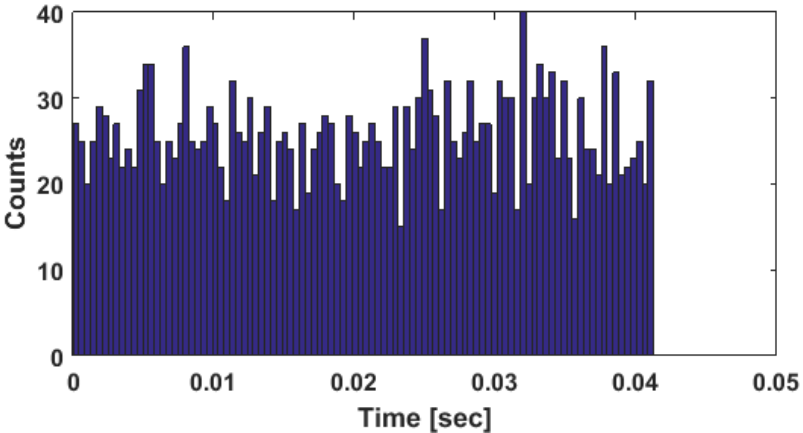
Cerenkov luminescence spectrum (energy [eV] vs. wavelength [nm])



Energy [eV]



Wavelength [nm]

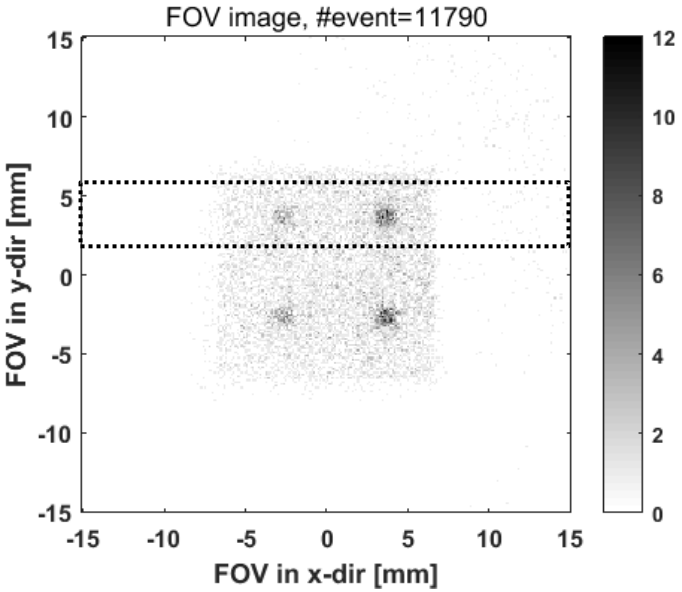


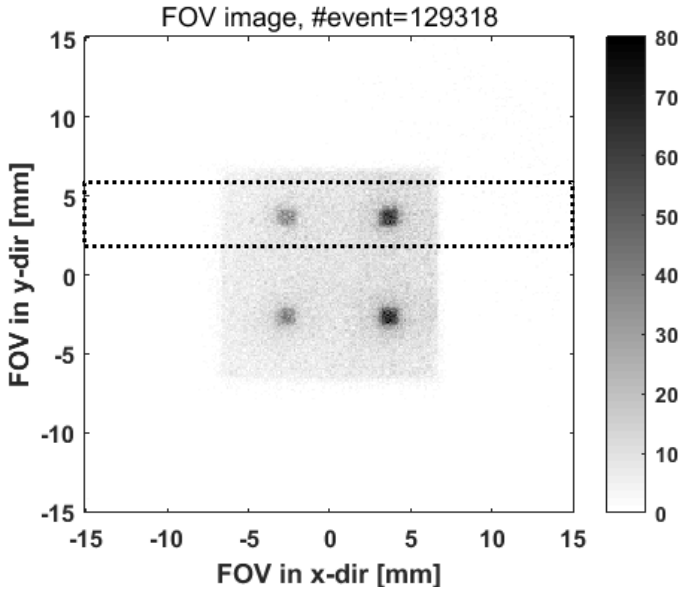
- Voxelized source (F-18)
- Voxelized phantom
- Acq= 0.04 sec

Cerenkov

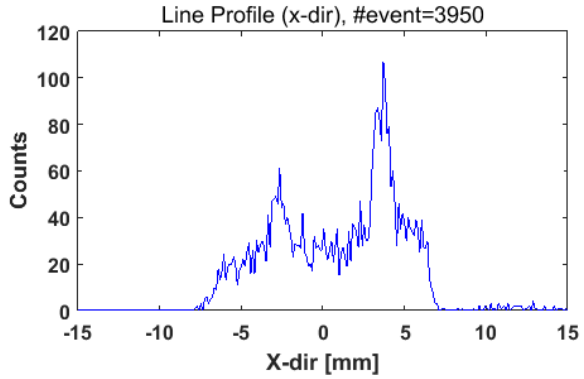
- Voxelized source (300 keV)
- Voxelized source (400 keV)

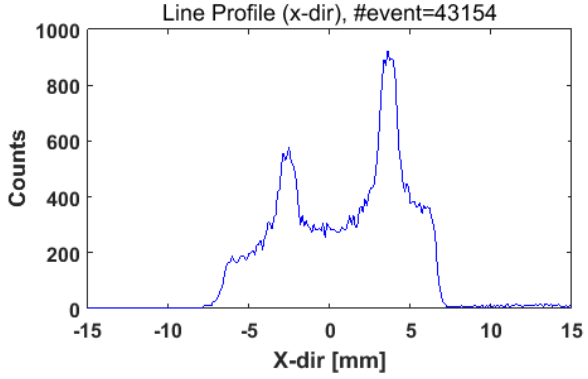
CCD image





Line profile

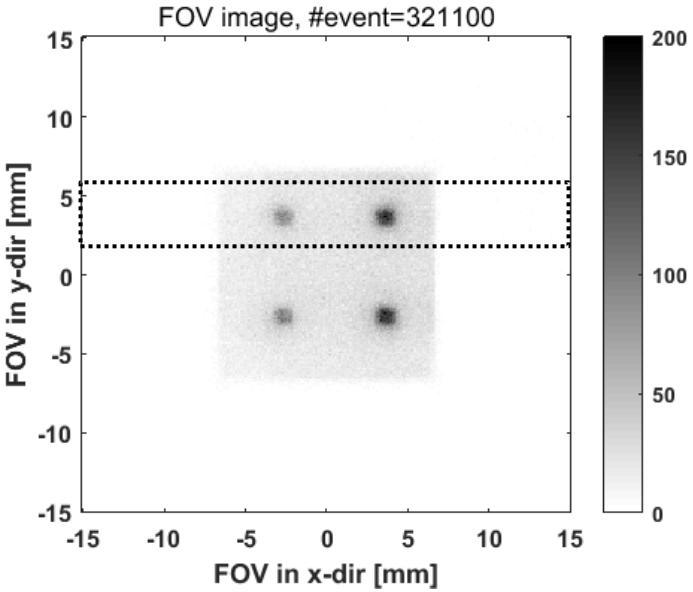


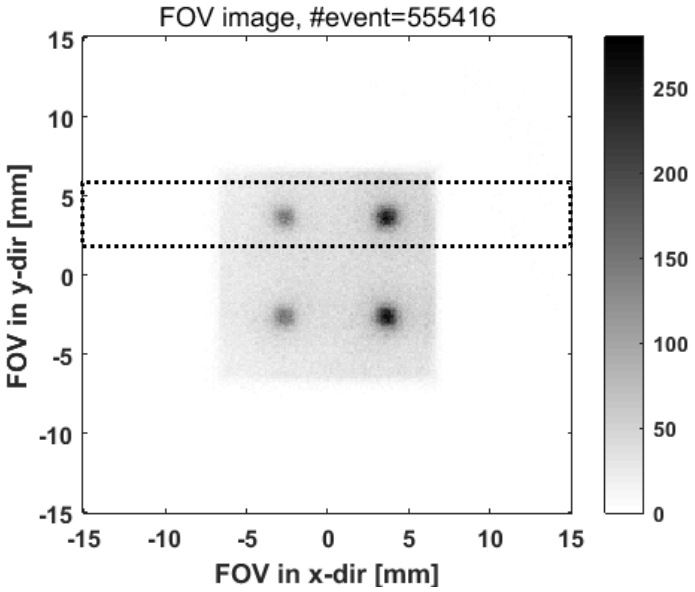


Cerenkov

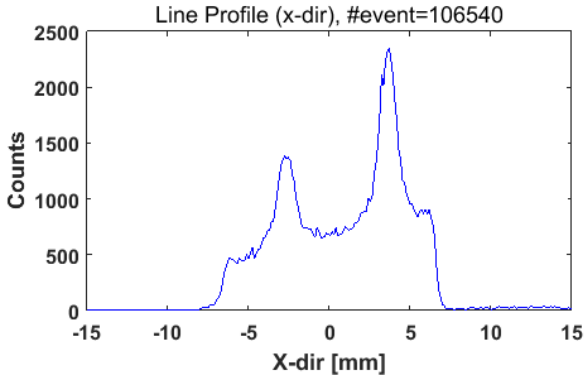
- Voxelized source (500 keV)
- Voxelized source (600 keV)

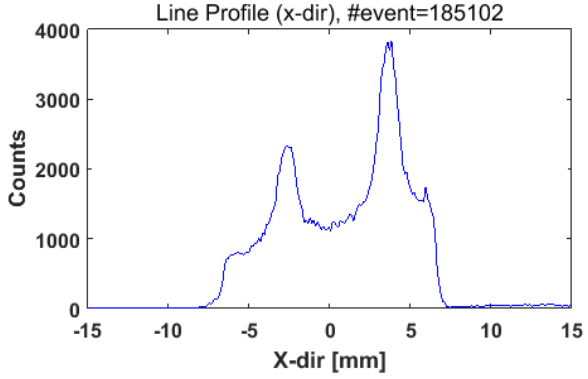
CCD image





Line profile



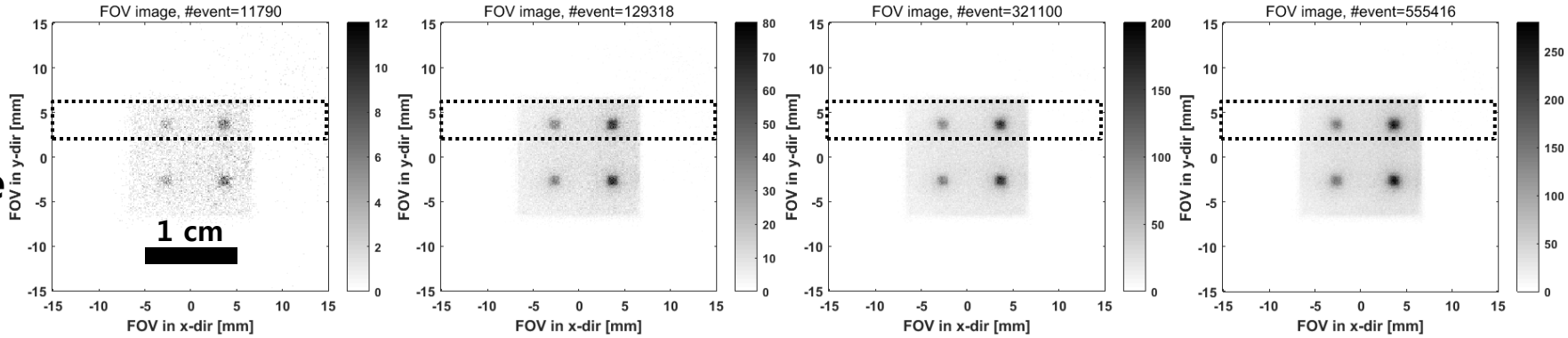


- Acq= 10 sec

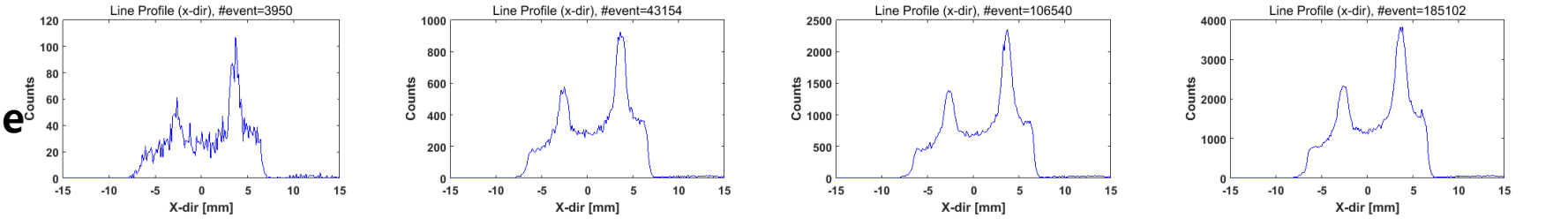
Cerenkov image with different positron energies

β+ energy **300 keV** **400 keV** **500 keV** **600 keV**

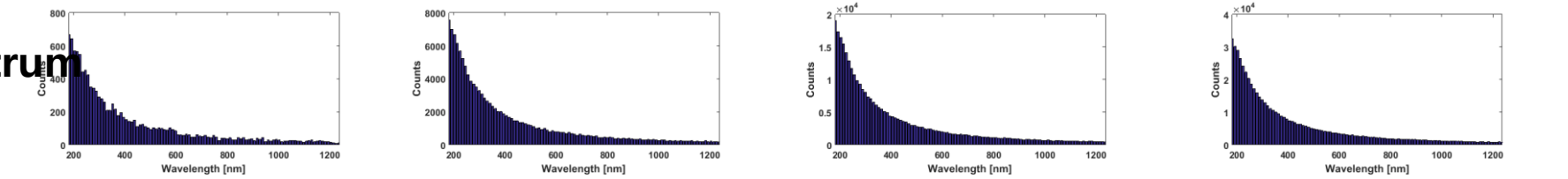
CCD image



Line profile



Spectrum



Cerenkov light yield as a function of positron kinetic energy