ImaSim Manual

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1. INTRODUCTION

1.1 PURPOSE

ImaSim is an interactive computer program aimed at simulating x-ray based medical imaging in a highly visual and intuitive way. This is to provide insight in some of the various components of the imaging chain.

1.2 WHAT IS COVERED

ImaSim covers the main medical imaging modalities using x-rays, namely planar kilovoltage (kV) imaging, planar megavoltage (MV) imaging or portal imaging, computed tomography (CT) imaging and cone beam computed tomography imaging (CBCT). Other x-ray imaging applications, such as industrial imaging, can also be simulated, provided their setups are similar to those of the medical modalities introduced above.

1.3 PHYSICS

The physics of *ImaSim* strives to balance the need for accuracy and computational speed. Compromises such as the absence of scattered radiation and simplistic detector modelling are balanced by accurate material cross sections and photon production algorithm.

1.4 MORE ON *IMASIM*

Additional information on *ImaSim* can be found here:

http://digitool.Library.McGill.CA:80/R/-?func=dbin-jump-full&object_id=67028&current_base=GEN01

The resource linked above is a McGill University master thesis. *ImaSim* was partially developed at McGill as part of a master's project. The thesis provides an in depth description of the algorithms used in *ImaSim*. It will be described as the physics manual in this document. The document you are reading is focused on the functionality of *ImaSim* and will not delve in depth into the physics or models of *ImaSim*.

1.5 CONVENTIONS

Throughout this manual when referring to user inputs/outputs or properties of windows such as buttons, menus, and plots, they will be in bold. The name given in the text will match the name in the software.

2. GETTING STARTED

2.1 INSTALLATION

ImaSim is simply installed by extracting the *ImaSim* folder from the downloaded archive. The folder is placed where the user desires, for example in **C:\Program Files** under windows and **/Applications** under OSX.

2.2 RUNNING *IMASIM*

ImaSim is launched by clicking on the **ImaSim_OSX...** icon found in the **ImaSim** folder in OSX and on the **ImaSim** icon/.exe found in the **ImaSim\ImaSim_WIN_...** folder on windows. See figure 1 on the following page.

2.3 SPLASH SCREEN

Launching *ImaSim* causes a splash screen to appear. A simple click will bring the user to the application.

2.4 START WINDOW

The **Start Window** is where the user is taken following the splash screen. It is from the **Start Window** that new simulations can be started or saved simulations loaded for review. It is also possible to launch the **Image Analysis Tool**. The **Start Window** is shown in figure 2.

To launch a new simulation, the user must first choose which modality he or she wishes to simulate. This is done by pressing the appropriate **SIMULATION TYPE** button, with **SIMULATION TYPE** being **PLANAR X-RAY, CT, PORTAL** or **CONE BEAM CT**.

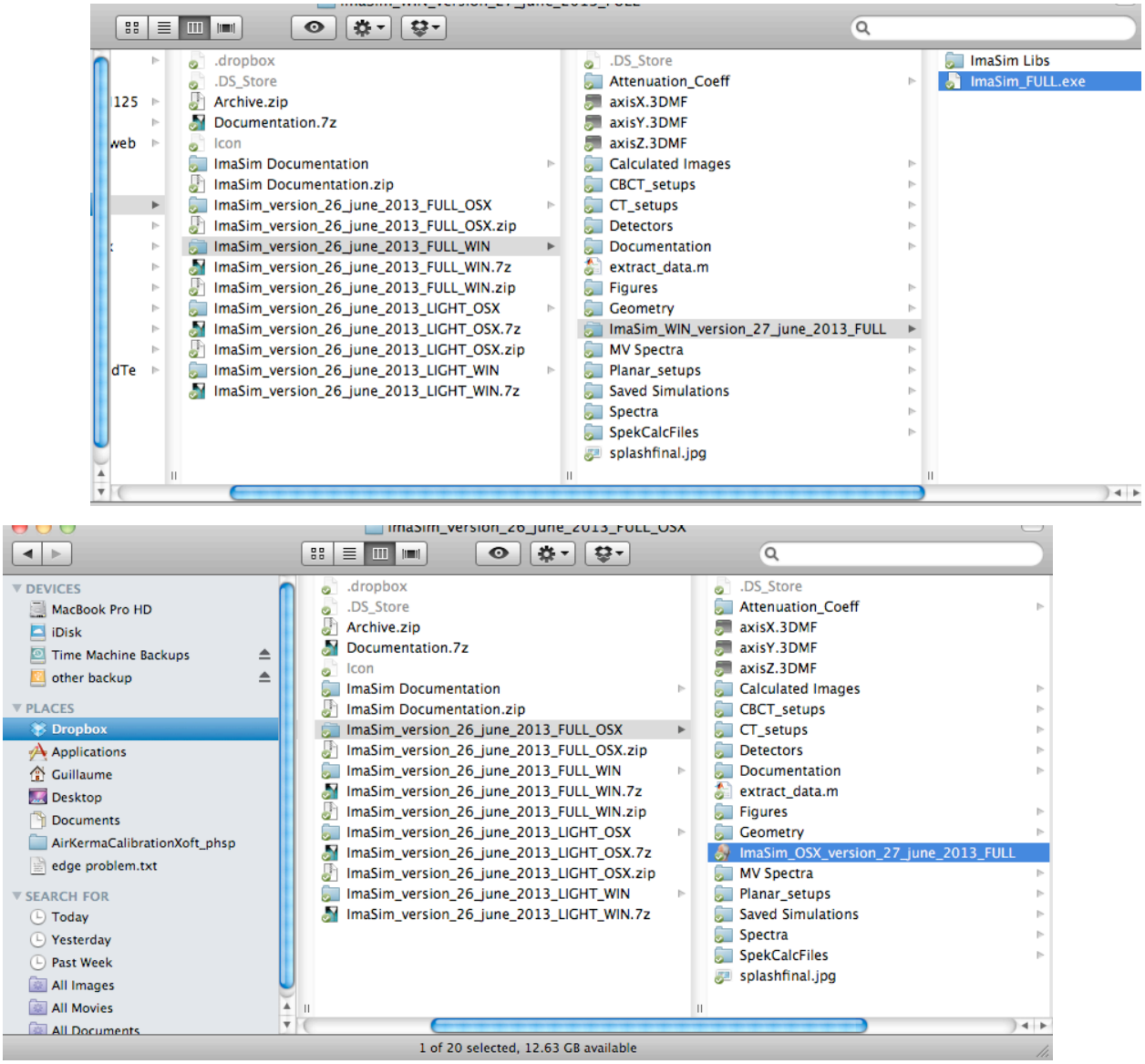

Fig. 1: Launching *ImaSim*. Top: windows. Bottom: OSX.

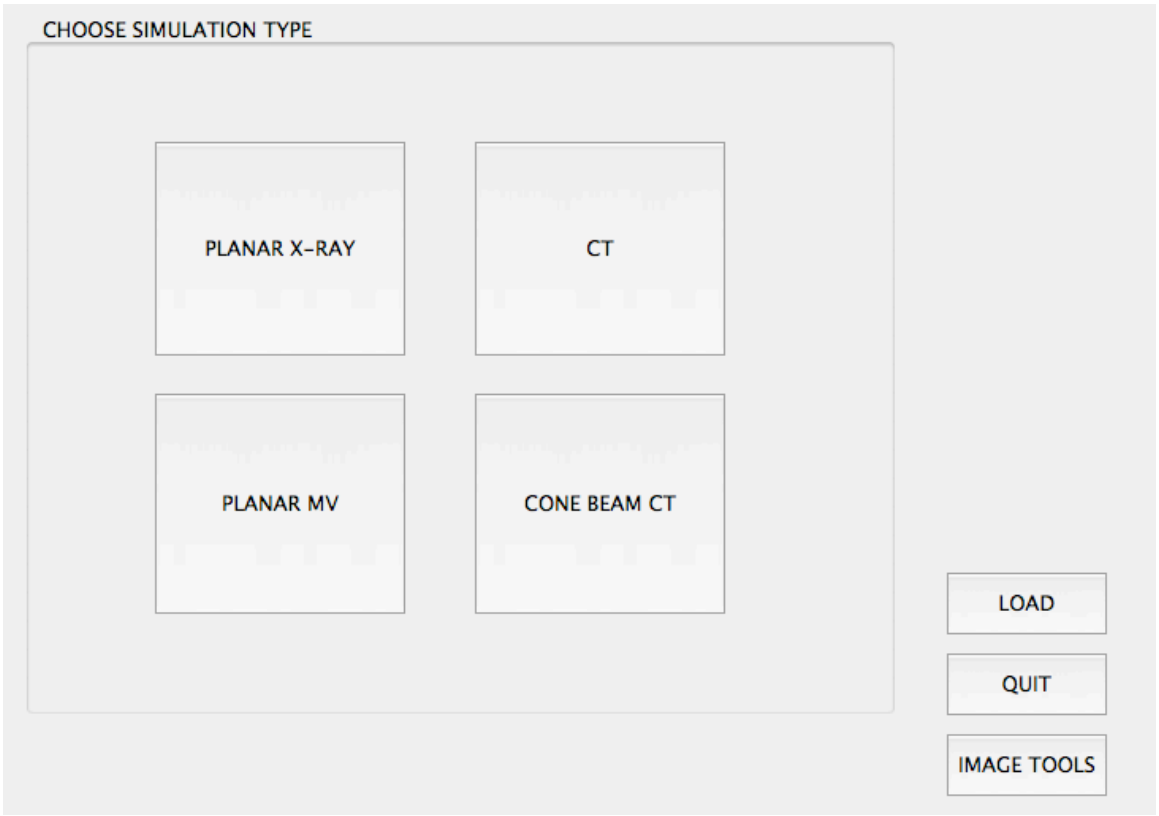

Fig. 2: The start window. A simulation is launched by pressing one of the four **SIMULATION TYPE** buttons.

3. CREATING A SIMULATION

3.1 MAIN SIMULATION WINDOW

Pressing one of the four **SIMULATION TYPE** buttons of the start window will launch a **Main Simulation Window**. Each modality has its own main simulation window, which will be discussed in detail in later sections. This section will introduce the main simulation window in general terms. The main simulation window as seen after pressing one of the four **NEW SIMULATION TYPE** buttons is shown in figure 3.

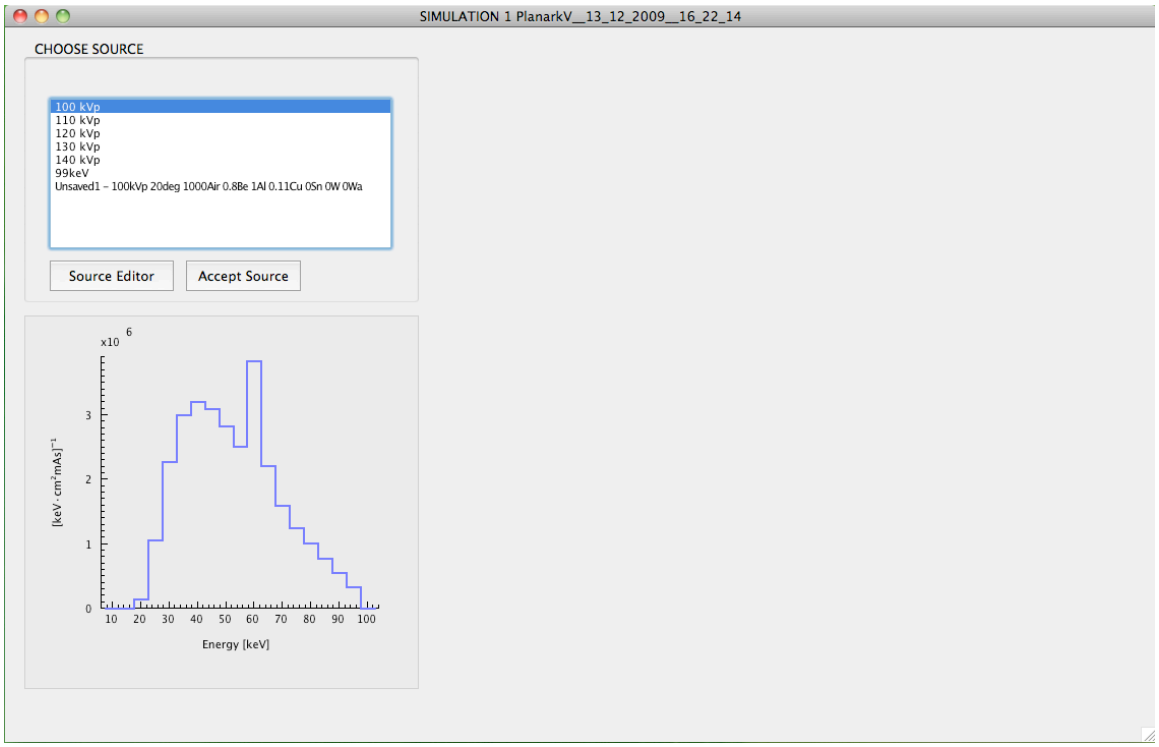

Fig. 3: The main simulation window right after clicking the **PLANAR X-RAY** button.

3.2 SOURCE SELECTION

The first step in any simulation is to select a source of photons. This is done in the **CHOOSE SOURCE** section of the main simulation window. Here a list of available sources is visible. As a source is highlighted, a plot of its spectrum is displayed. If the user desires to create a new source, he clicks the **Source Editor** button which launches the **Source Editor Window**.

3.2.1 Note on editor windows

Editors are available to modify a component of a simulation. It is possible to modify x-ray sources, objects to image and imaging setups (position of source, object and detector in space). These editors will be presented in full detail in later sections. For the moment we will assume the user does not need to open an editor.

3.3 OBJECT SELECTION

Once the source has been accepted by pressing the **Accept Source** button, the **CHOOSE OBJECT** section of the **Main Simulation Window** becomes visible. This is shown in figure 4. The same approach as in Source Selection is taken here. The highlighted object is displayed as a 3D rendering. It is again possible to open the **Object Editor Window** (by pressing the **Open Editor** button) to modify or create a new object, or press **Accept Object** to move on. Clicking and dragging rotates the view in the 3D world and mouse scrolling zooms in and out. The mouse must be hovering over the 3D area.

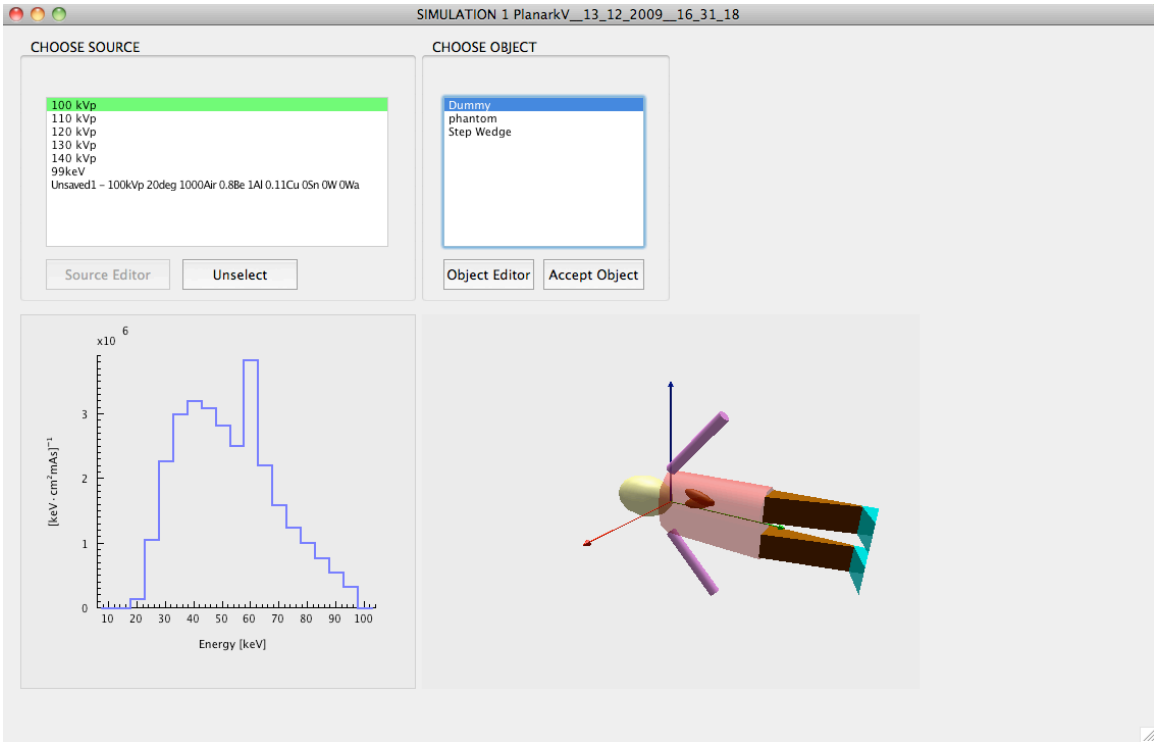

Fig. 4: The main simulation window following source selection.

3.4 SETUP SELECTION

Once the object is selected, the user moves on the **CHOOSE SETUP** section. This is shown in figure 5. Again the same approach. A highlighted setup will be displayed in the 3D area as a white sphere at the position of the source, a green shape taking the shape of the radiation field and a grey plane showing the detector. The **Setup Editor Window** can be opened to modify the setup. Unlike the **Source Editor Window** and **Object Editor Window**, which are modality independent, the **Setup Editor Window** has a different variant for planar (kV and MV share the same), CT and CBCT imaging.

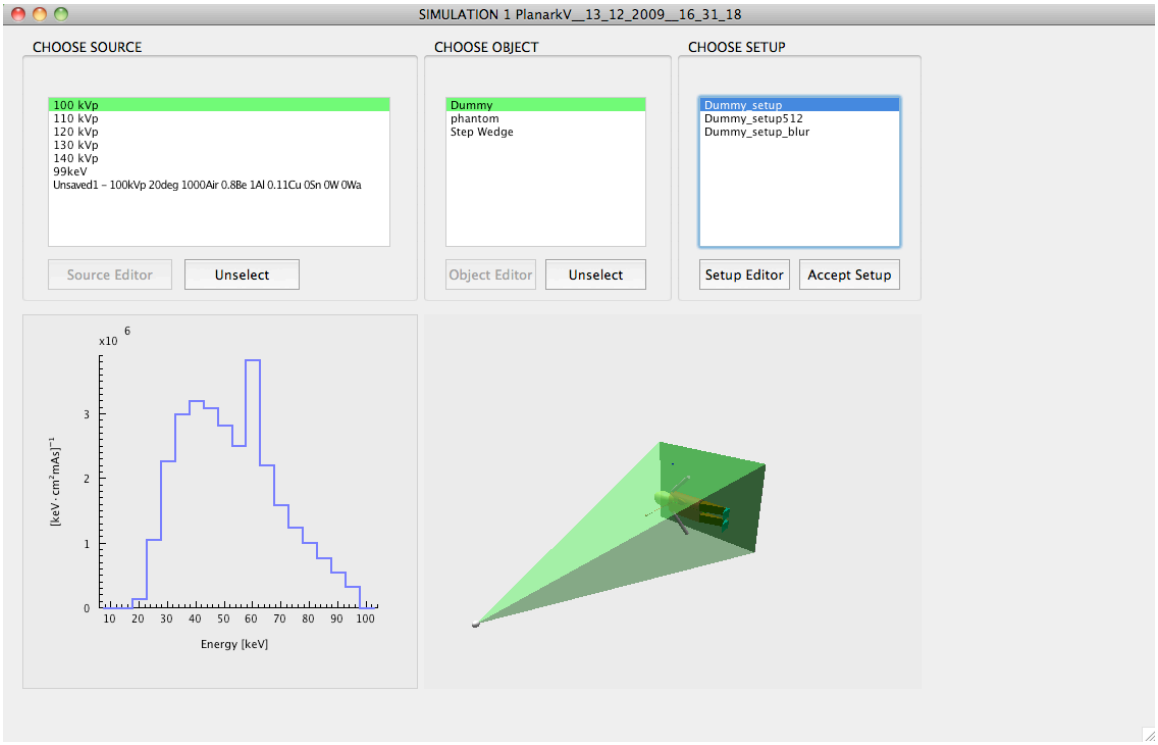

Fig. 5: The setup selection section.

3.5 DETECTOR SELECTION

The selection of the detector type is shown in figure 6. Unlike the previous selections, detector selection does not have an editor. This is because detector modelling in *ImaSim* is based on energy response curves that have been obtained from the literature or precalculated by Monte Carlo methods. These curves give, for a photon of a given energy reaching the detector, the fraction of absorbed energy. Additional information on these curves is found in the physics manual. The detection of photons will be explained in a later section of this manual.

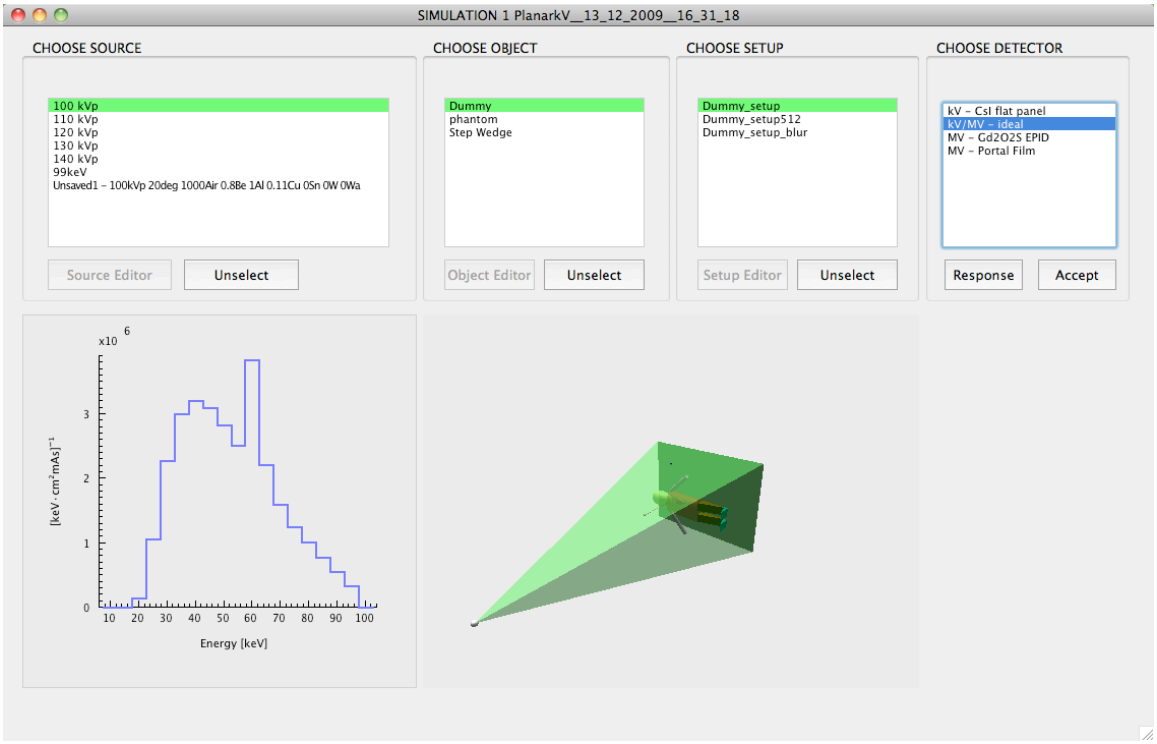

Fig. 6: Detector type selection

3.5.1 Detector energy response window

The user can visualize the energy response curve of a given detector by pressing the **Response** button. This opens the **Detector Energy Response** window; a small plot window where the energy response curve is shown over the energy range of the selected source. This is shown in figure 7. It is possible to show the spectrum (**Show Spectrum Shape** checkbox) overlaid onto the plot with arbitrary units. Checking the **Show Effective Spectrum** checkbox will display the spectrum multiplied by the energy response curve. This spectrum will be renormalized so its maximum is unity.

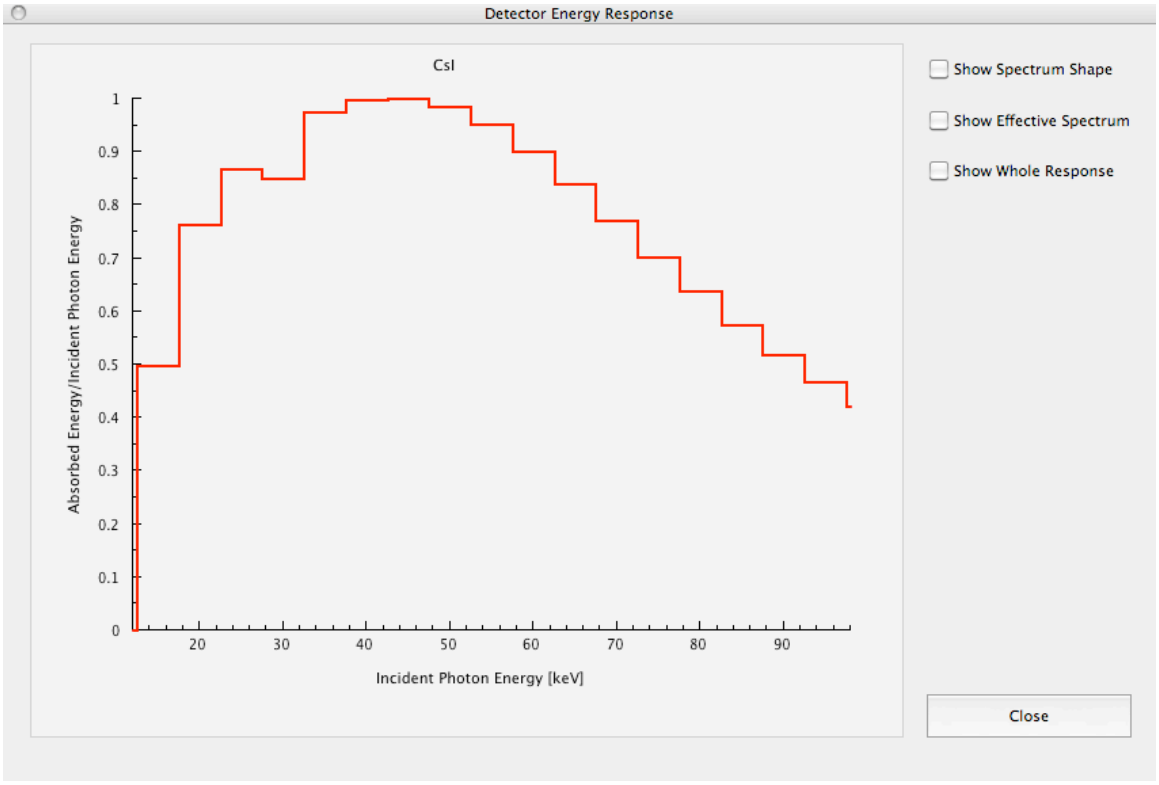

Fig. 7: The energy response window.

The third checkbox, **Show Whole Response**, displays the response curve over the complete energy range provided by the data.

3.6 RUN SIMULATION

Once all selections have been made, the **Run Simulation** button appears. In the case of planar kV imaging some additional options appear in the form of checkboxes. These will be discussed later in this manual. Figure 8 shows a simulation ready to be launched. At any point before launching the simulation, the user can unselect one of the selections and choose something different. Pressing the **Run Simulation** button will start the transportation of photons from the source to detector points. A progress bar shows the progression of these calculations.

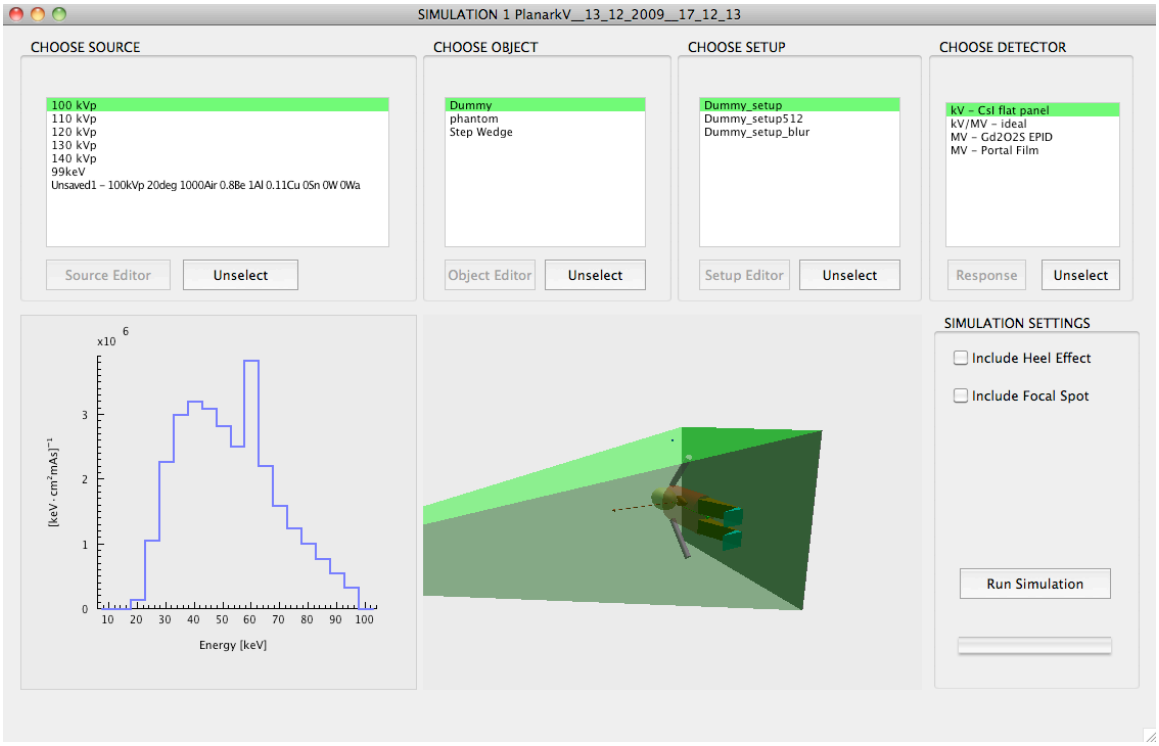

Fig. 8: A simulation where all selections have been made.

4. EDITORS

4.1 KV SOURCE EDITOR

It is possible to create photon sources in the 10-300 kV range using the **Source Editor** window. It is shown in figure 9.

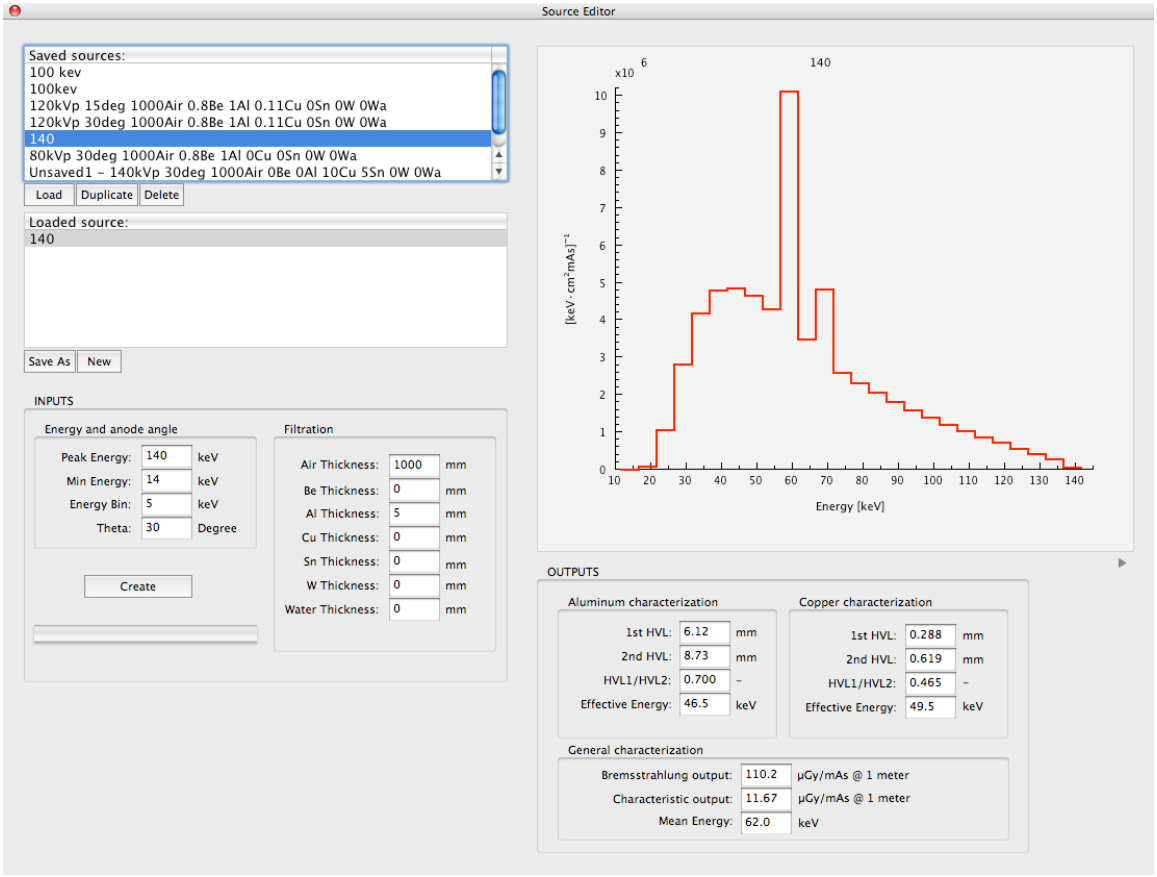

Fig. 9: The kV source editor.

The **Saved sources** list box shows sources that are saved on disk. It is possible to load them into the **Loaded source** list box. Only one source can be loaded at a time.

The user starts by pressing the **New** button. This sets all parameters to default values. The following table lists the parameters the user can modify and their ranges.

Table 1: Parameters of the kV editor.

Parameter	Minimum value	Maximum value
Peak energy	10 keV	300 keV
Min energy	0.1 * Peak energy	Peak energy
Energy bin width	0.1 keV	-
Target angle	1 degree	89 degrees

It is also possible to add filtration in mm of several materials. Pressing the **Create** button will generate the spectrum using the specified inputs. The model used to calculate spectra is fully described in a pair of papers[1,2]. The calculation will provide the spectrum at the center of the field. The target angle is theta in the next figure.

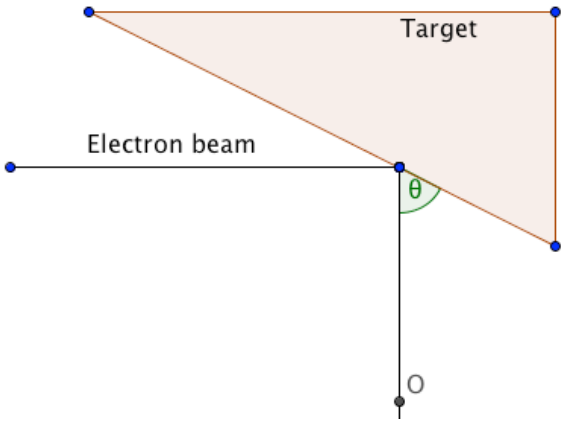

Fig. 10: The target angle is represented by theta.

After the calculation the spectrum will be plotted as a histogram. Other outputs are also provided, both in copper and aluminum:

[1] Poludniowski and Evans. Calculation of x-ray spectra emerging from an x-ray tube. Part I. Electron penetration characteristics in x-ray targets. Med. Phys. (2007) vol. 34 (6) pp. 2164-2174
[2] Poludniowski. Calculation of x-ray spectra emerging from an x-ray tube. Part II. X-ray production and filtration in x-ray targets. Med. Phys. (2007) vol. 34 (6) pp. 2175-2186

- First and second half value layers (HVL)
- Homogeneity coefficient HVL_1/HVL_2
- Effective energy
- The above both in Al and Cu
- Mean energy
- Bremsstrahlung output
- Characteristic output

Once a satisfactory spectrum is generated, pressing the **Save As** button will enable to user to save it to disk. A generic name is provided and it is suggested to replace with something meaningful and descriptive. The spectrum will now be shown in the **CHOOSE SPECTRUM** section of the **Main Simulation Window** and will be available for simulations requiring kV sources.

4.2 OBJECT EDITOR

ImaSim provides the user with the ability to image custom objects. These user created objects are made with an object editor containing a three dimensional viewing environment. Objects created in *ImaSim* are based on four different building blocks: rectangular prisms, elliptical cylinders, ellipsoids and right triangular prisms (see figure 11). An object consists of one or more of such building blocks. Each block has an assigned material with density and mass attenuation coefficients from the web database XCOM. They can be translated in three directions and rotated around three object axes. Multiple rotations are carried out in order, with rotations around the x axis executed first, then around the y axis and finally around the z axis. The blocks also have three parameters each governing their size and shape.

To account for overlap, blocks are assigned a priority number. Given two overlapping blocks, the intersection volume will have the physical properties of the higher priority block. It is also possible to assign a color and transparency to each block to make them distinguishable.

The **Object Editor** is shown in figure 12. The **Geometries** list box shows which imaging geometries have already been designed. Double clicking on one of them or highlighting one and pressing the **Edit** button will load it into the editor.

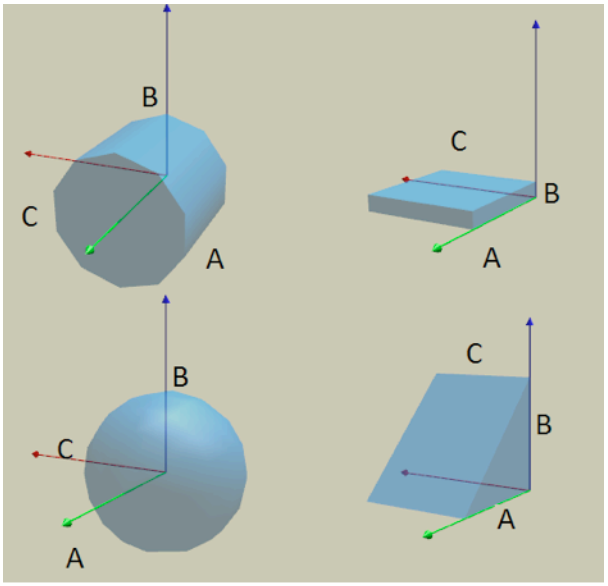

Fig. 11: The four basic building blocks with their object rotation axes and shape parameters A, B and C. The x (y z) axis is green (red blue).

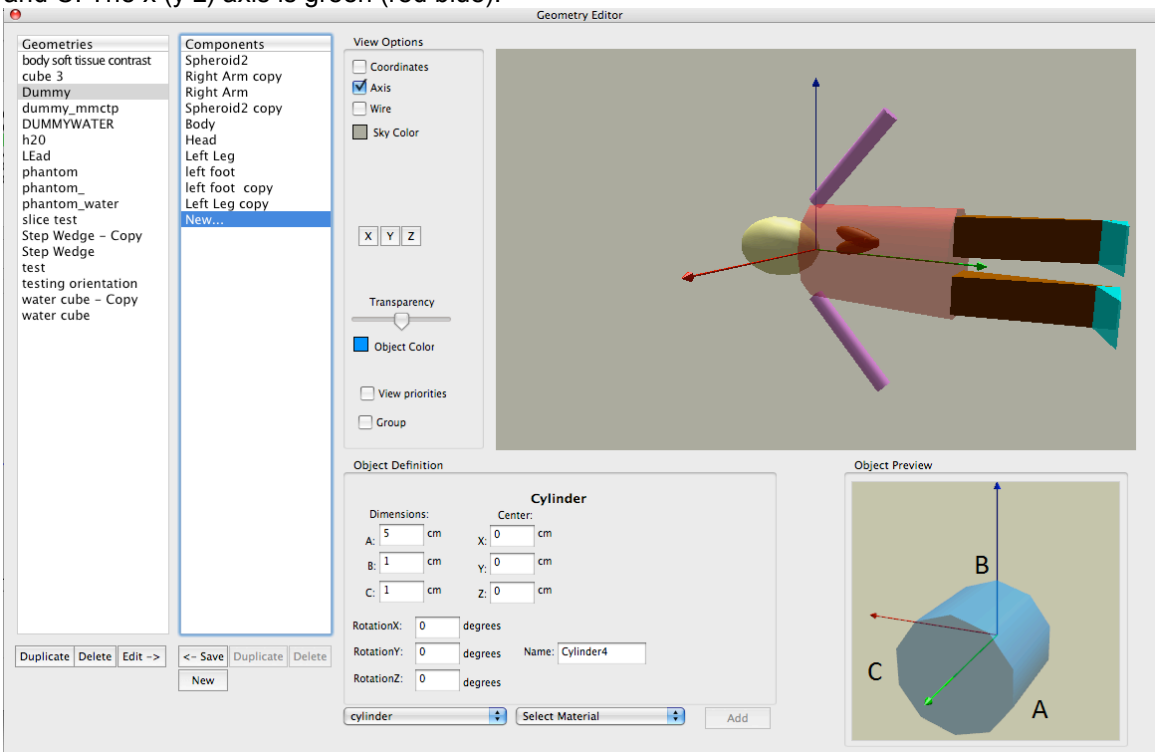

Fig. 12: The object editor is shown here. Each object is a collection of building blocks having their own parameters. Colors and transparency can be assigned to each block in the three dimensional environment.

The **Components** list box shows all the building blocks used in a given geometry. Blocks are given generic names by default which can be changed by the user.

To add a new block to the list of components, the **New...** item in the list box must be highlighted. The first thing to do is to select the type of building block. The three shape parameters as well as the three rotations and shifts can then be modified. A material is selected as well. Pressing the **Add** button will add a building block with the given name to the component list as well as to the 3D world.

It is possible to change the priority order of a building block by dragging its name in the component list upwards or downwards. To visualize the effect of priority number, the **View priorities** check box can be ticked. This shows all components in the same color and higher priority objects become opaque while low priority objects are transparent.

It is also possible to check the **Group** check box and give group translations to the objects.

When the geometry is complete, the **Save** button is pressed and the geometry is saved to disk with a meaningful name.

4.3 SETUP EDITOR

Once a photon source and object have been selected, they need to be positioned in space with respect to a detector. *ImaSim* provides a three dimensional Cartesian coordinate system where this positioning takes place. The object has its own absolute coordinate system and the source and detector are positioned in another coordinate system, which can be translated with respect to the object's system. The goal is to provide the user with the freedom to create various imaging geometries.

Three different geometrical setup types are present in *ImaSim* : planar imaging, single slice CT and CBCT. In planar imaging, the beam covers a rectangular detector, forming a rectangular based pyramid. In single slice CT, the beam covers a one dimensional arc-shaped detector array, forming a fan. Finally in CBCT, the beam covers a square detector array, forming a square pyramid. The parameters for each case are listed and described in tables 2-4.

The editors are shown in figures 13-15. The **Saved setups** list box shows setups for a given type of modality which have been saved and are available. Again, it is possible to load them. The **Loaded setup** list box shows which setup is currently displayed/being edited. Once modifications have been done, the **Save as** button will be pressed to save the setup to disk.

Most parameters can be varied interactively with the use of a slider.

4.3.1 Planar imaging

Table 2: Parameters of a planar imaging setup. Numbers in parenthesis represent the number of degrees of freedom associated with the parameter.

Parameter	Description
Source to origin distance (1)	The distance between the focal spot and the coordinate system's origin.
Detector to origin distance (1)	The distance between the detector's center and the coordinate system's origin.
Origin position (3)	The position of the origin with respect to the object.
Detector size (2)	The two dimensional size of the rectangular detector.
Number of detectors (1)	This governs the resolution of the image. To have isotropic resolution, the number of detectors is specified in one direction only.
Detector translation (2)	Translation of the detector only in the two dimensions perpendicular to the source to origin vector.
Source detector rotation (3)	Rotation of the source and detector system around the three axes of the coordinate system.

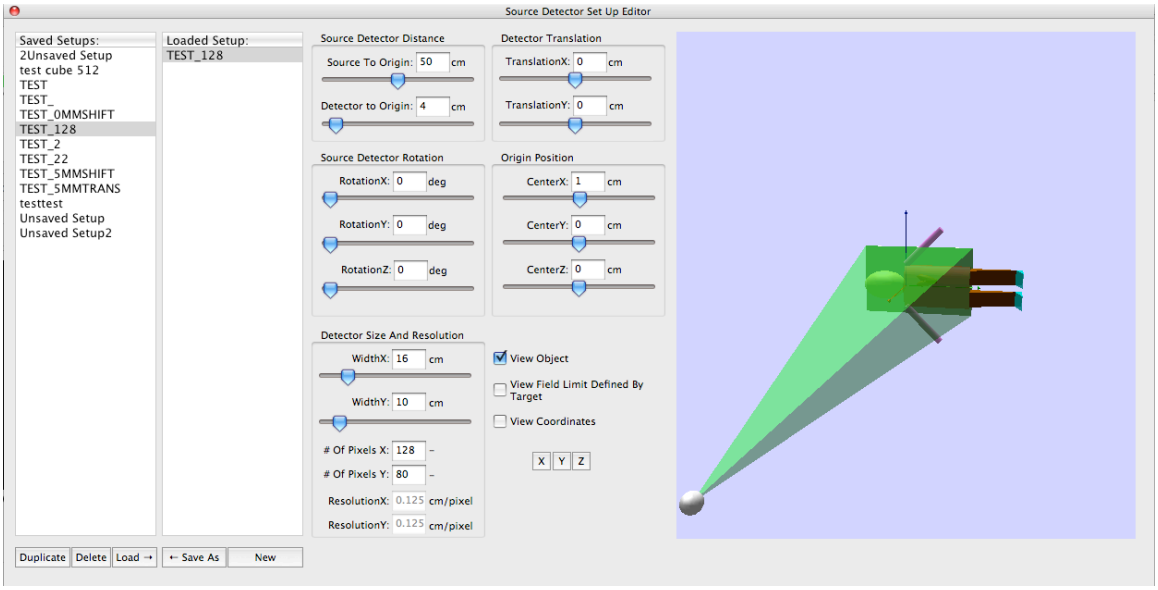

Fig. 13: The setup editor for planar imaging is shown here. Parameters are varied interactively with sliders and their effect on the setup are shown in the three dimensional environment. Visible are the source (sphere), beam (pyramid), detector (plane) and object.

All parameters shown in figure 13 can be modified aside from **ResolutionX** and **ResolutionY**, which are governed by the size of the detector (**WidthX** and **WidthY**) and **# Of Pixels in X** and **# Of Pixels in Y**. To ensure isotropic resolution, only **# Of Pixels in X** can be modified, the resolution given by this value and **WidthX** provide a resolution which is then applied in the Y direction. This resolution gives the number of pixels in Y.

The **View Field Limit Defined By Target** check box, when checked, shows a plane which is the edge of the field from the angle of the target. Beyond this plane, no photons are present.

4.3.2 Single slice CT imaging

Table 3: Parameters of a single slice CT imaging setup. Numbers in parenthesis represent the number of degrees of freedom associated with the parameter.

Parameter	Description
Source to origin distance (1)	The distance between the focal spot and the coordinate system's origin.
Detector to origin distance (1)	The distance between the detector's center and the coordinate system's origin.
Source detector rotation (3)	Rotation of the source and detector system around the three axes of the coordinate system.
Origin position (3)	The position of the origin with respect to the object.
Fan angle (1)	The angular width of the fan beam.
Slice thickness (1)	In the case of a multiple slice scan, this sets the distance between slices.
Scan length (1)	When this parameter is larger than the slice thickness, more than one slice will be acquired.
Number of detectors (1)	This governs the resolution of the one dimensional array.
Number of views (1)	The number of projections around the object.

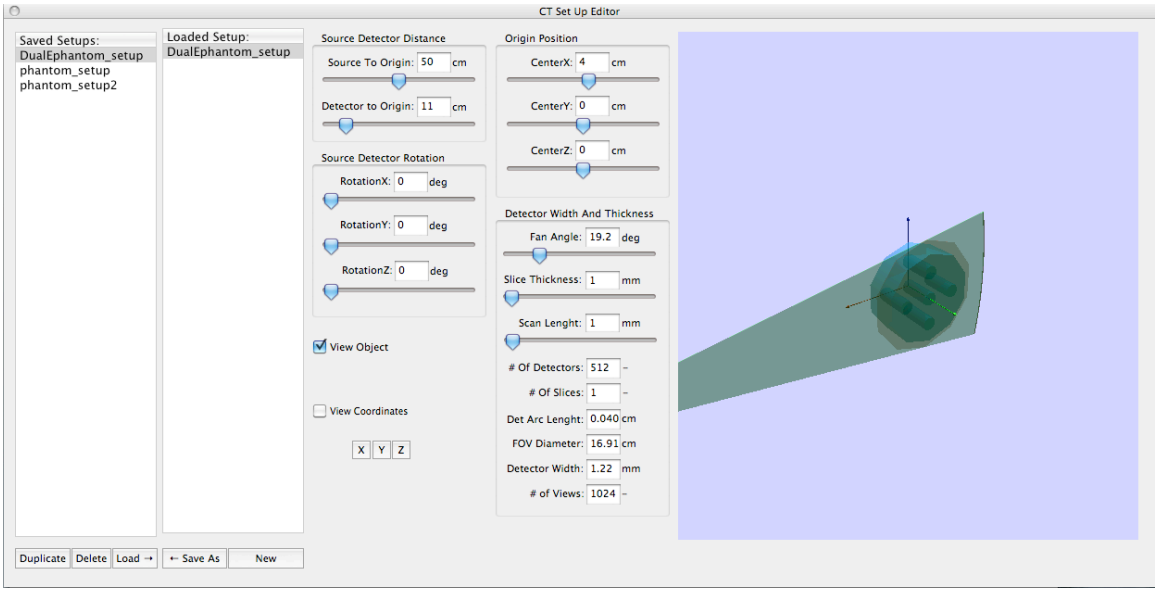

Fig. 14: The setup editor for CT imaging. The beam is fan shaped.

Again here, most parameters can be modified. Parameters which are dictated by others and thus cannot be modified are the **Det Arc Length** which is the arc length of a single detector element (along the fan), **FOV Diameter** which is governed by the **Source to Origin** and **Fan Angle** parameters, **Detector width** which is the thickness of the detector array in the direction transverse to the fan. This value is different than slice thickness since this is specified at the isocenter. **The # Of Slices** is also not user defined, but depends on **Scan Length** and **Slice thickness**.

The fact that **Scan Length** and **Slice Thickness** can be set means that for a simulation, multiple slices can be acquired. Of course this requires longer calculation times.

4.3.3 CBCT imaging

Table 4: Parameters of a CBCT imaging setup. Numbers in parenthesis represent the number of degrees of freedom associated with the parameter.

Parameter	Description
Source to origin distance (1)	The distance between the focal spot and the coordinate system's origin.
Detector to origin distance (1)	The distance between the detector's center and the coordinate system's origin.
Source detector rotation (3)	Rotation of the source and detector system around the three axes of the coordinate system.
Origin position (3)	The position of the origin with respect to the object.
Detector width (1)	The size of the square detector array.
Number of detectors (1)	The number of detectors along one side of the array. Governs resolution.
Number of views (1)	The number of projections around the object.

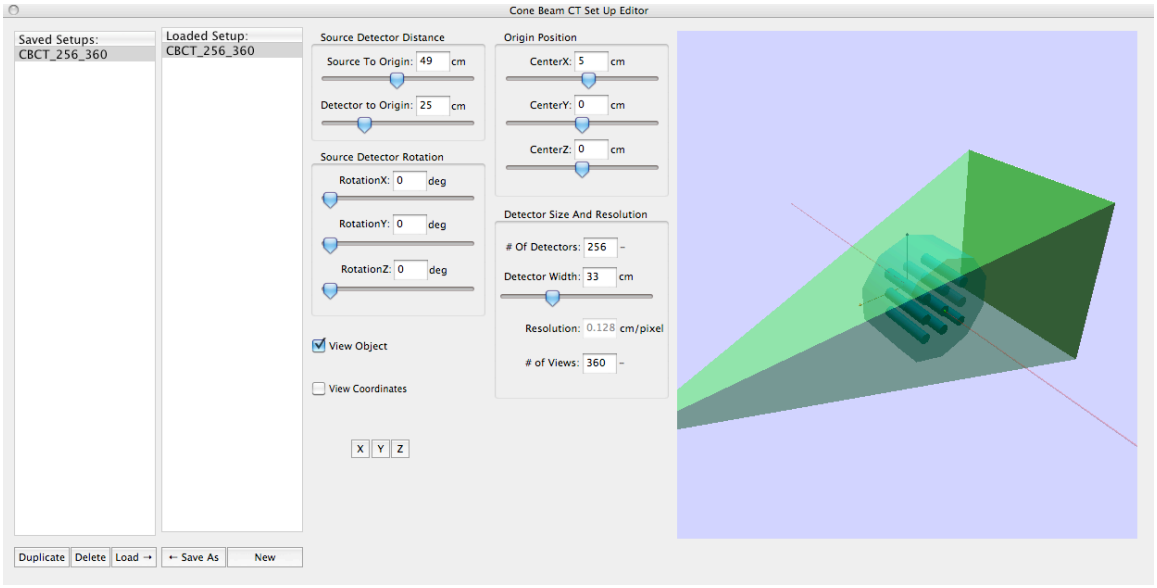

Fig. 15: The setup editor for CBCT imaging. The axis of rotation is in red.

In this case, only the **Resolution** parameter is not user defined. The rest can be modified. Resolution is isotropic and the detector array is square.

4. CALCULATION TIMES

Calculation times are proportional to a few parameters. We are discussing calculation times related to transporting photons from the source to the detector. These are the parameters which matter:

- Number of bins in spectrum
- Number of detector elements in detector
- Number of views in CT simulations
- Number of slices in single slice CT simulations

It is recommended not to use very large numbers for these quantities. Some recommended values are given below:

- Number of bins in spectrum (about 100)
- Number of detector elements in detector

A. For planar imaging (256 x 256 is ok, 512 x 512 can be slower but still ok)

B. For CT imaging (256 is a bit coarse but fast, 512 is decent)

C. For CBCT imaging (256x256 can be long, 128 is faster but coarse)

- Number of views in CT simulations

D. For CT (360, can be a bit coarse, 720 slower)

E. For CBCT (360)

- Number of slices in single slice CT (Will increase a normal calculation times X fold)

Calculation times for CBCT simulations are generally quite long given the amount of data to be simulated. It is therefore not recommended to run CBCT simulations “online” but better to run them prior to a lecture or demonstration and save the results. The simulation can then be reopened and the steps repeated

but without the calculations being redone. More on this in the **Loading Simulations Section**.

5. GOING THROUGH SIMULATIONS

5.1 PLANAR X-RAY IMAGING

Once a source, object, setup and detector response have been selected, the user is ready to launch the photon transport. Two more options are available: simulate heel effect and simulate focal spot. These options are only available for planar x-ray imaging and only one at a time can be selected.

5.1.1 Heel effect

The heel effect is included by checking the **Include Heel Effect** checkbox before pressing the **Run Simulation** button. When simulating the heel effect, the target filtration is calculated for every detector row in the cathode anode direction. This means that a different spectrum and absolute number of photons are specified per detector row. This entails some calculation overhead since for each row, a spectrum must be recalculated.

5.1.2 Focal spot

The effect of a finite focal spot can be included by checking the **Include Focal Spot** checkbox before pressing the **Run Simulation** button. To simulate the effect of a finite focal spot, the user specifies the cross sectional size of a square electron beam impinging on the angled target. In addition to the size, the user specified the number of bins in each direction. The square area of the beam is divided into bins which are projected onto the angled anode. For each bin, a 2D projection is calculated as if the center of the bin was a point source of photons. This means that calculation time is increased by a factor corresponding to the number of sampling bins.

5.1.3 Results

Once the user has set up the simulation, he presses the **Run Simulation** button. Once calculations are over, he presses the **View Results** button to see

a 2D projection image (figure 16). Values are normalized to 10000 (0 attenuation). The user can inspect the results and change window and level. By scrolling while the mouse cursor is over the image, the user can zoom in and out.

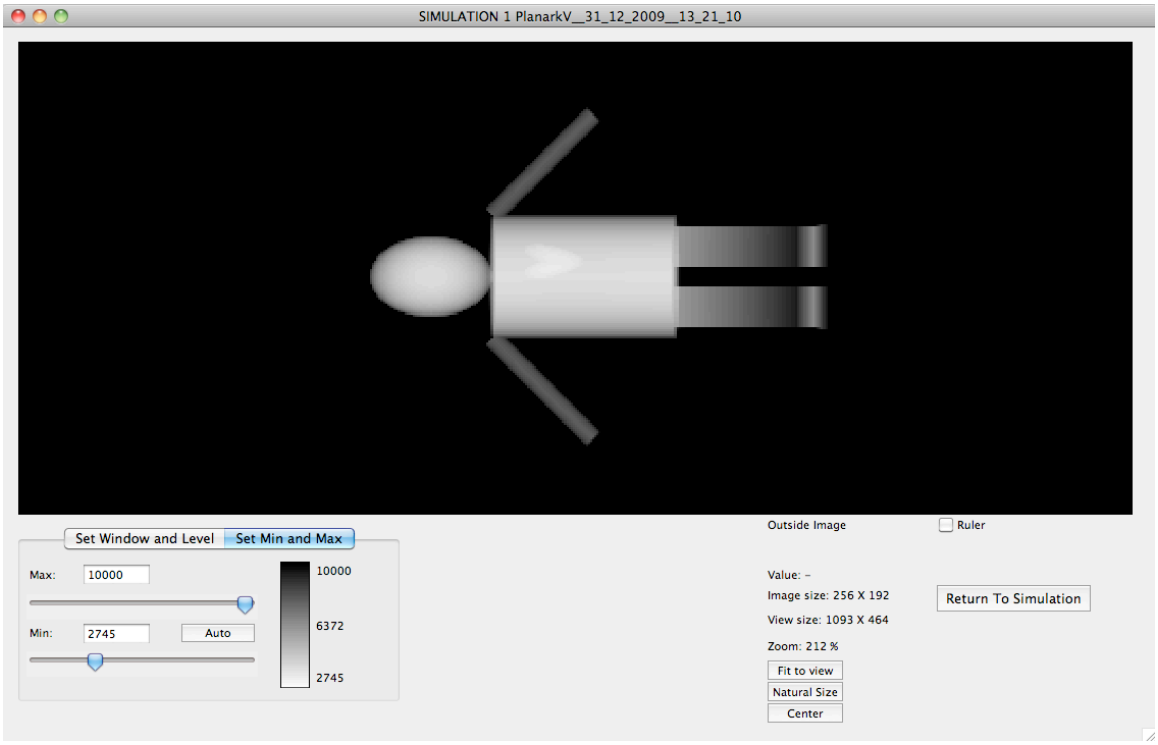

Fig. 16: Results of planar x-ray imaging simulation.

5.1.4 Saving

At this point the user can close the simulation. He will be offered to save his results. If the user wants to analyze them with the built-in image tools, he needs to save them.

5.2 PORTAL IMAGING

A portal imaging simulation will be quite similar to a Planar X-Ray simulation. The main difference is that there is no source editor for MV beams because MV photon spectra are provided with *ImaSim* (obtained from literature). There are no options to simulate focal spot finite size.

5.3 SINGLE SLICE CT

5.3.1 Live sinogram

Before running the simulation for CT imaging, it is possible to select the live sinogram option. This is done by checking the **View Sinogram Formation** checkbox. This will show the construction of the sinogram projection by projection and can be insightful when introducing the notion of sinogram.

5.3.2 Fan sinogram

Once photon transport is over, the user can visualize the sinogram. This sinogram is called a fan sinogram since it is related to the fan beam geometry of the beam. The bottom axis is the projection angle and the vertical axis is the angle in the fan beam associated to a detector element. To simplify things, this sinogram is converted into the sinogram one would obtain by scanning the object with parallel beam geometry. More on this in the physics manual. This is done by pressing the **Convert to Parallel** button. See figure 17.

Fig. 17: Fan sinogram.

5.3.3 Parallel sinogram

When conversion is complete, the window will look like figure 18. At this point, pressing the **Return to Fan** button lets the user review the differences between fan and parallel sinograms by going back to the fan sinogram. Pressing the **Convert to Parallel** button again returns the parallel sinogram, without recalculating everything.

The user is now ready to backproject the image using the filtered backprojection algorithm. See physics manual for a detailed explanation of the algorithm. The user specifies an image size (**Image Size** edit field) for the backprojection, as well as a filter (**Choose filter...** popup menu).

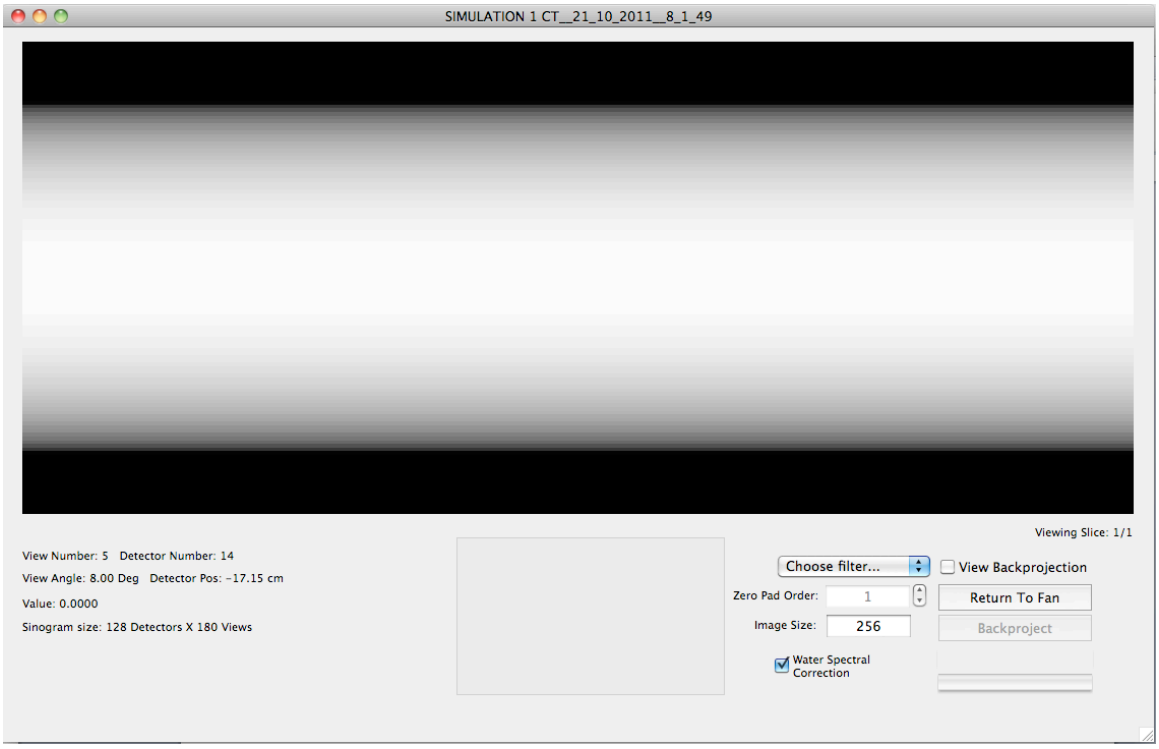

Fig. 18: Parallel sinogram and settings for back projection.

He selects a filter from the drop down menu. It is also required to provide the zero pad order. Values can range from 0 to 3, with default of 1. A zero pad order of 0 will pad an array of 127 elements to 128, and leave a 128 elements array unchanged. A zero pad order of 1 will extend both arrays to 256 elements. This is necessary for the Fourier transform. The **Water Spectral Correction** checkbox enables a rudimentary beam hardening correction algorithm based on a water correction. This is now different than the approach presented in the physics manual. Prior to backprojection, the algorithm calculates real projections and ideal projections through varying thicknesses of water, up to the maximum value found in the sinogram. A look-up table is generated, and for a given attenuation value in the sinogram, the corresponding ideal value is assigned. This is expected to work well for water, but not for bone.

Once all parameters are entered, the **Backproject** button is pressed and the backprojection is calculated. It is possible to check the **View**

Backprojection checkbox to be able to view the backprojection projection by projection.

5.3.4 Result

Once the backprojection is complete, the user sees the image, as in figure 19. This figure lets the user modify window and level as well as zoom in out by scrolling with mouse cursor above image. The image values are in Hounsfield units (HU).

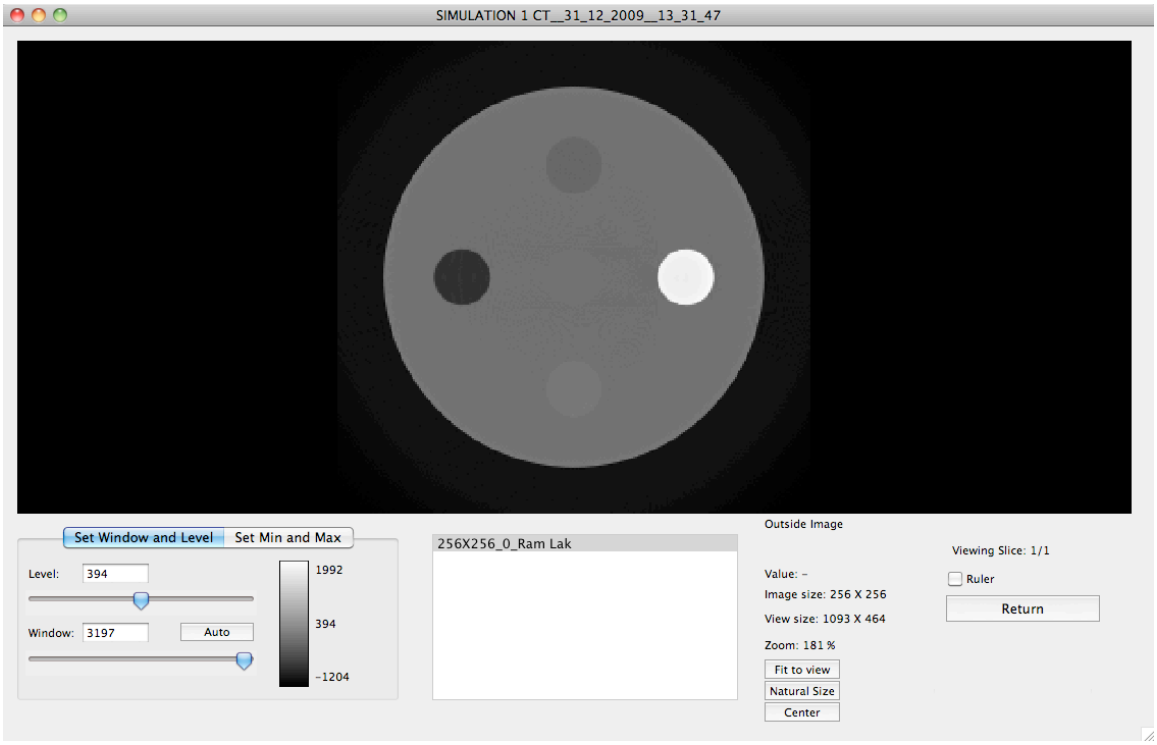

Fig. 19: Result window of a CT simulation.

The list box shows the images that have been calculated, with their size and filter. It is possible to press the **Return** button and do a new backprojection with different parameters. All images will be kept.

Again, upon closing, the user is asked whether he wishes to save his simulation.

5.3.5 Changing filter

Pressing the **Return** button will bring the user back to the window of figure 18 where he can change the filter, image size and enable or disable the beam hardening correction. He then presses **Backproject** again to obtain a new image, which can be compared to the previous one.

5.4 CBCT

5.4.1 Projections

After all projections are acquired, the user can see them by pressing the **Results** button. The software will take a little time (roughly 30 seconds for a 256x256 detector with 360 projections) to load all projection data into images. Once this is complete, it is possible, by scrolling the mouse *outside* the image of projections, to scroll though the projection. This is shown in figure 20.

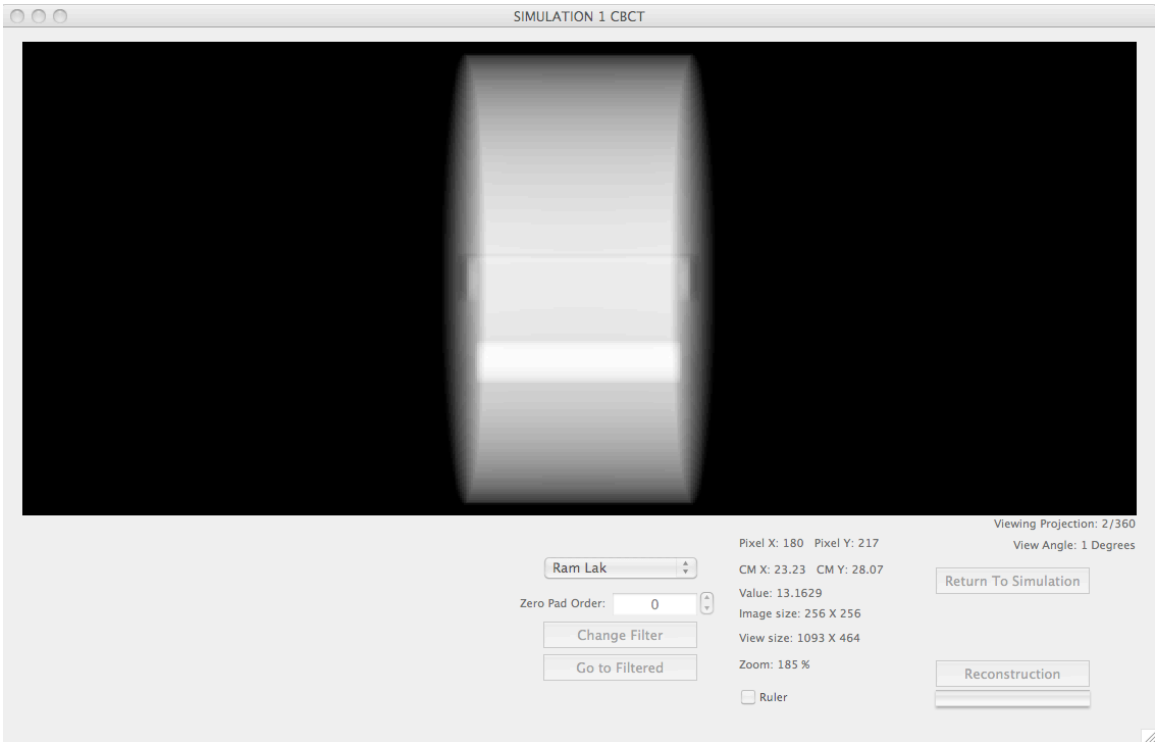

Fig. 20: The projections of a CBCT simulation.

The user must now filter the projections (according to the FDK reconstruction algorithm, details in physics manual). He selects a filter from the drop down menu. It is also required to provide the zero pad order. Values can range from 0 to 3, with default of 1. A zero pad order of 0 will pad an array of 127 elements to 128, and leave a 128 elements array unchanged. A zero pad order of 1 will extend both arrays to 256 elements. This is necessary for the Fourier transform. Pressing the **Filter** button launches the calculations which can be

time consuming. Again the option to correct for beam hardening is available (see section 5.3.3).

5.4.2 Filtered projections

Once the filtration is done, the user will see the filtered projections as in figure 21. Again scrolling through projections is possible. When the user is ready to backproject, he presses the **Reconstruction** button.

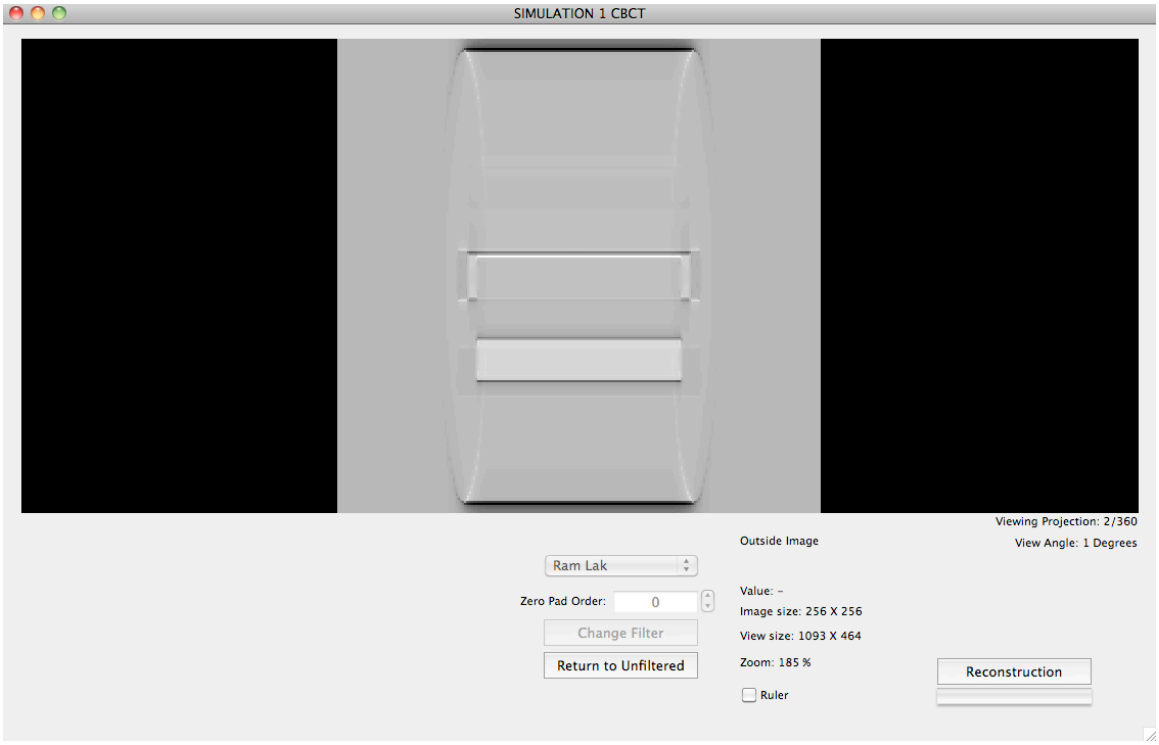

Fig. 21: Filtered projections.

5.4.3 Reconstruction

The user must then choose the reconstruction plane. This is done via the window shown in figure 22.

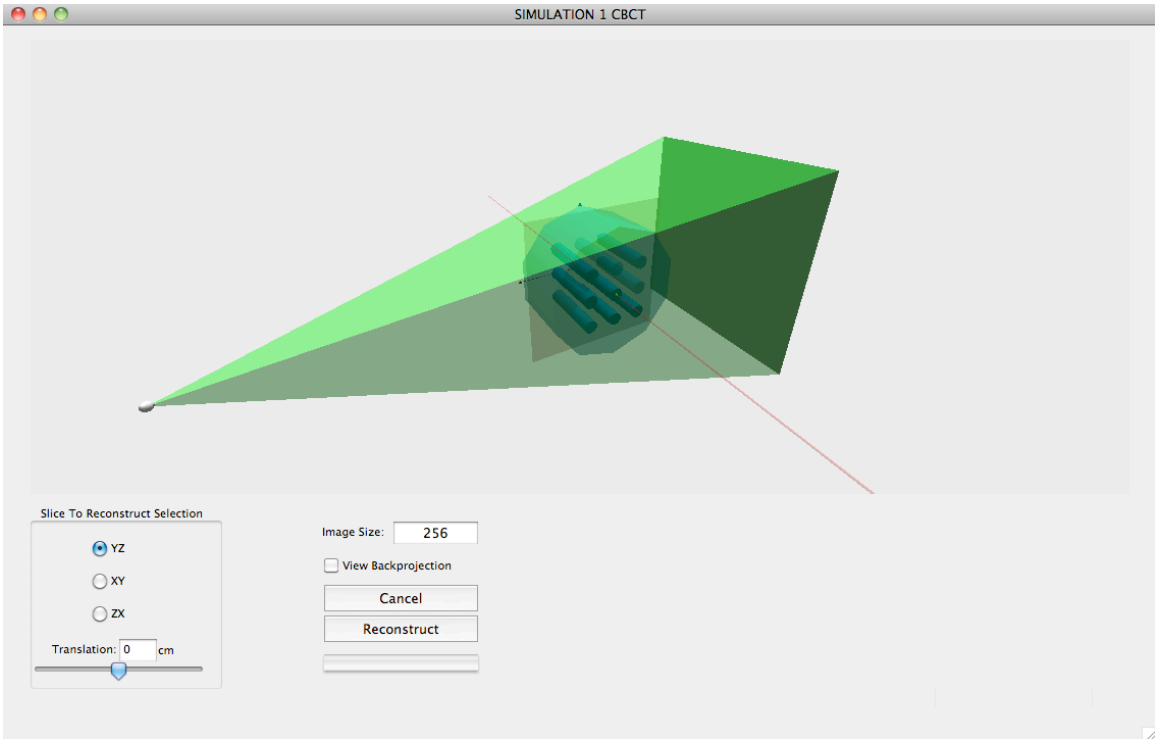

Fig. 22: Reconstruction plane selection.

The image plane can be oriented in three directions YZ, XY or ZX. It is also possible to translate it. Once the reconstruction plane is selected, as well as image size, the **Reconstruct** button is pushed. It is again possible to view the backprojection projection by projection. When the calculation is complete (it takes similar times as for CT) the user can see the result.

5.4.4 Result

The result window is quite similar to the one from CT. It is shown in figure 23. Values are in HU. The list box shows all reconstructed images, as well as the plane in which they were reconstructed, their image size and the filter used.

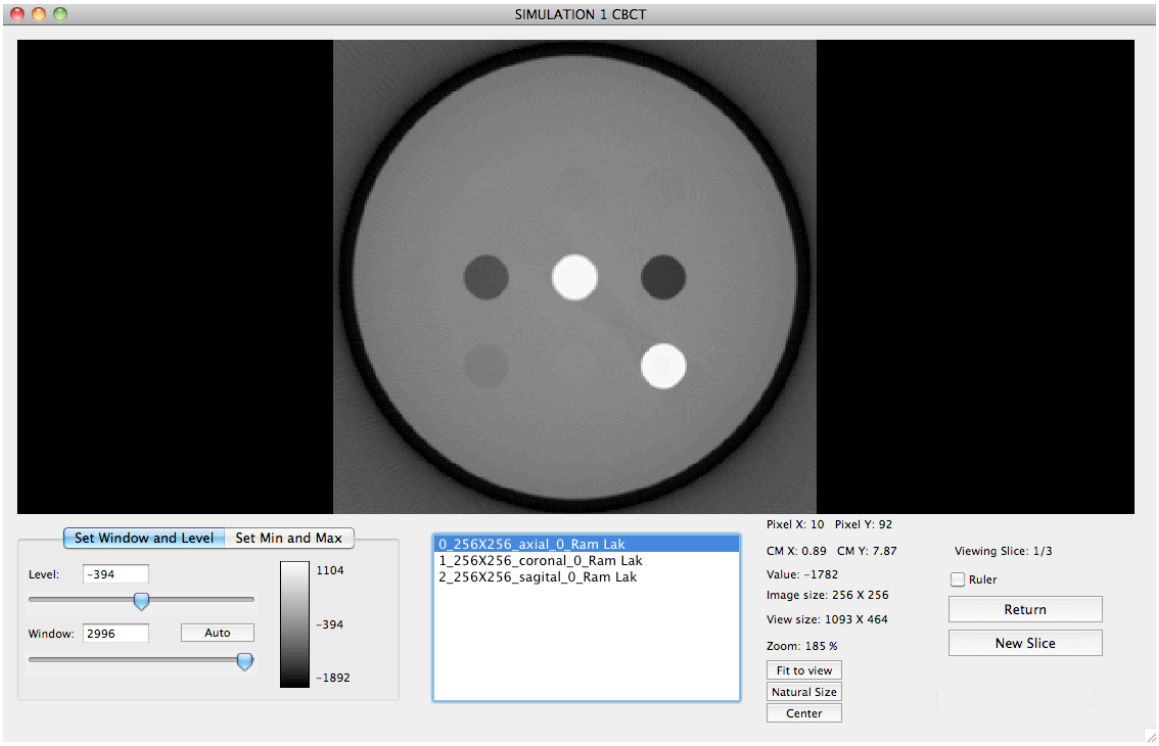

Fig. 23: Results from CBCT.

Again, upon closing, the user is asked whether he wishes to save his simulation. It is highly recommended to save CBCT simulations since they take a long time to calculate.

5.4.5 Changing filter

It is always possible to come back to the unfiltered projections by pressing first the **Return** button (fig. 23) and then the **Return to Unfiltered** button (fig. 21). At this point, pressing the **Change Filter** button will erase the filtered projections and let the user recalculate with a new filter. This will take some time again.

6. LOADING SIMULATIONS

It is possible to load a saved simulation to review all the steps taken to produce the final results. At the **Start Window**, the user presses the **LOAD** button and gets the screen shown in figure 24.

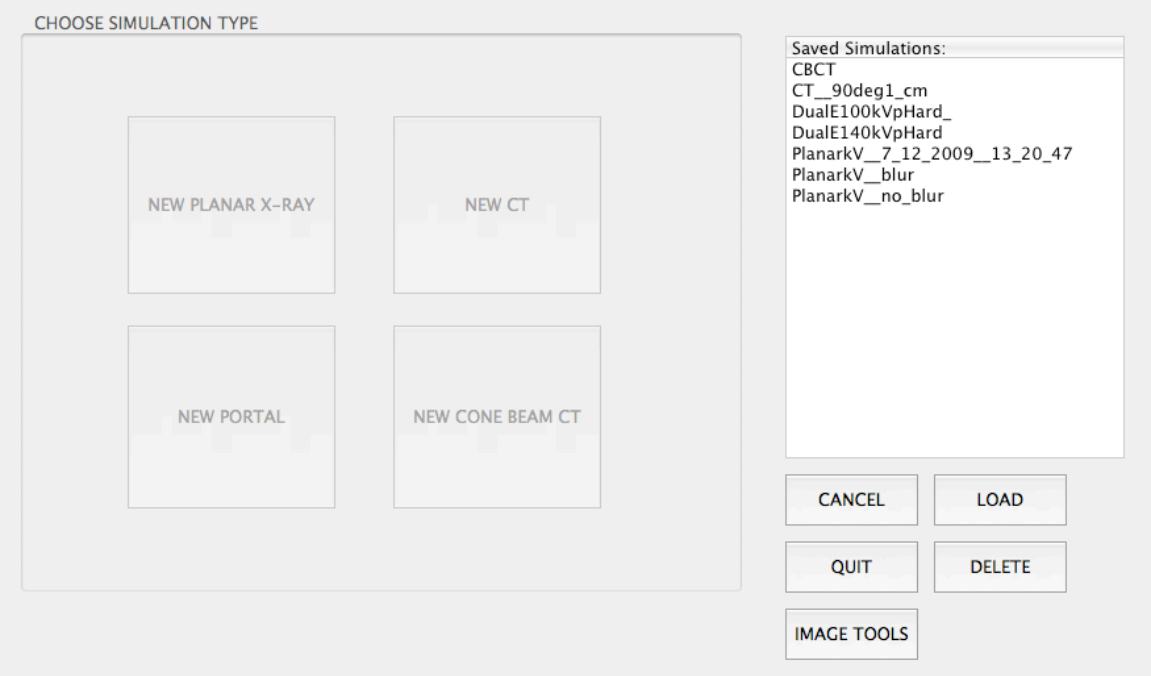

Fig. 24: The start window in Load mode. Saved simulations are shown in the list box.

All the simulations that have been saved are shown in the **Saved Simulations** list box. Highlighting a saved simulation and pressing the **LOAD** button again will open a simulation window showing the selected inputs, as in figure 25.

Notice that all Editor buttons are disabled. This is only to review what was used. Pressing the same buttons as when running the simulation will take the user through the steps taken, finally arriving at the results.

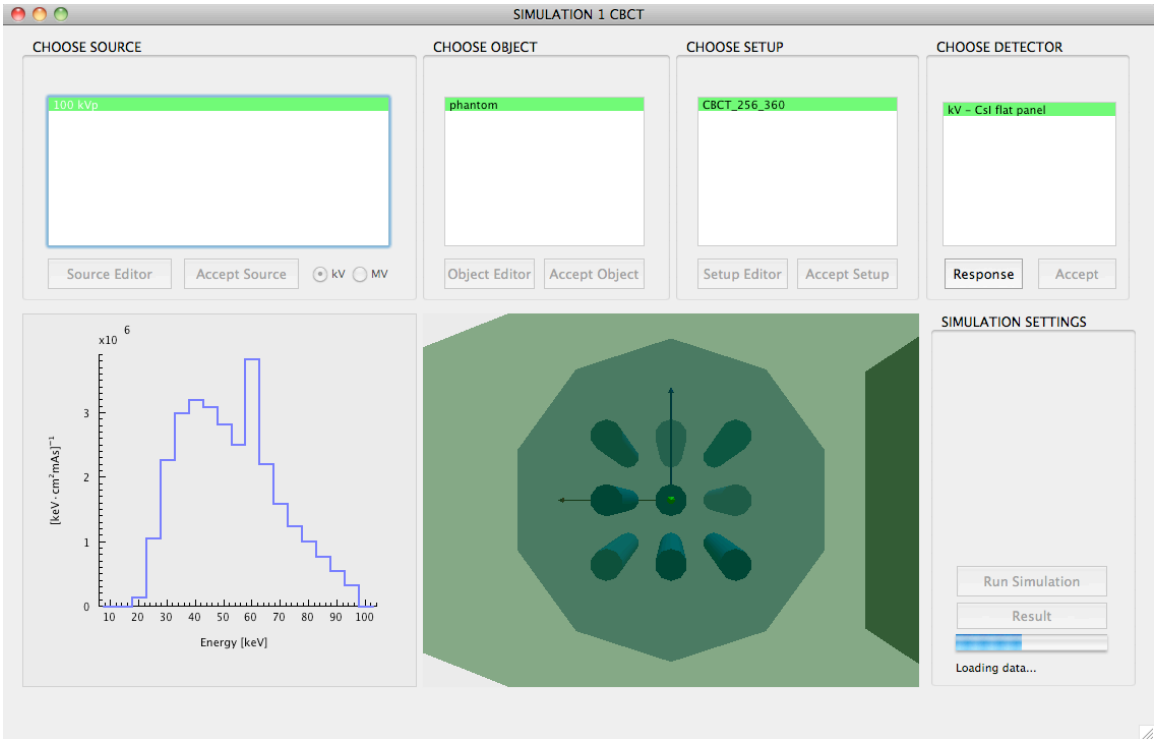

Fig. 25: A loaded CBCT simulation. Visible are all the inputs selected.

When a simulation is saved, the files associated with the source, object, and set up are kept in a special folder. This means that even if the user deletes some of these files from the general libraries when editing sources for example, he will still be able to load the simulation.

Going back to figure 24, a highlighted simulation can be deleted by pressing the **DELETE** button.

7. IMAGE ANALYSIS

Images from saved simulations can be studied in depth with an image analysis module built in *ImaSim*. To launch it, the user presses the **IMAGE TOOLS** button in the **Start Window** (Figure 2). This will open the window shown in figure 26.

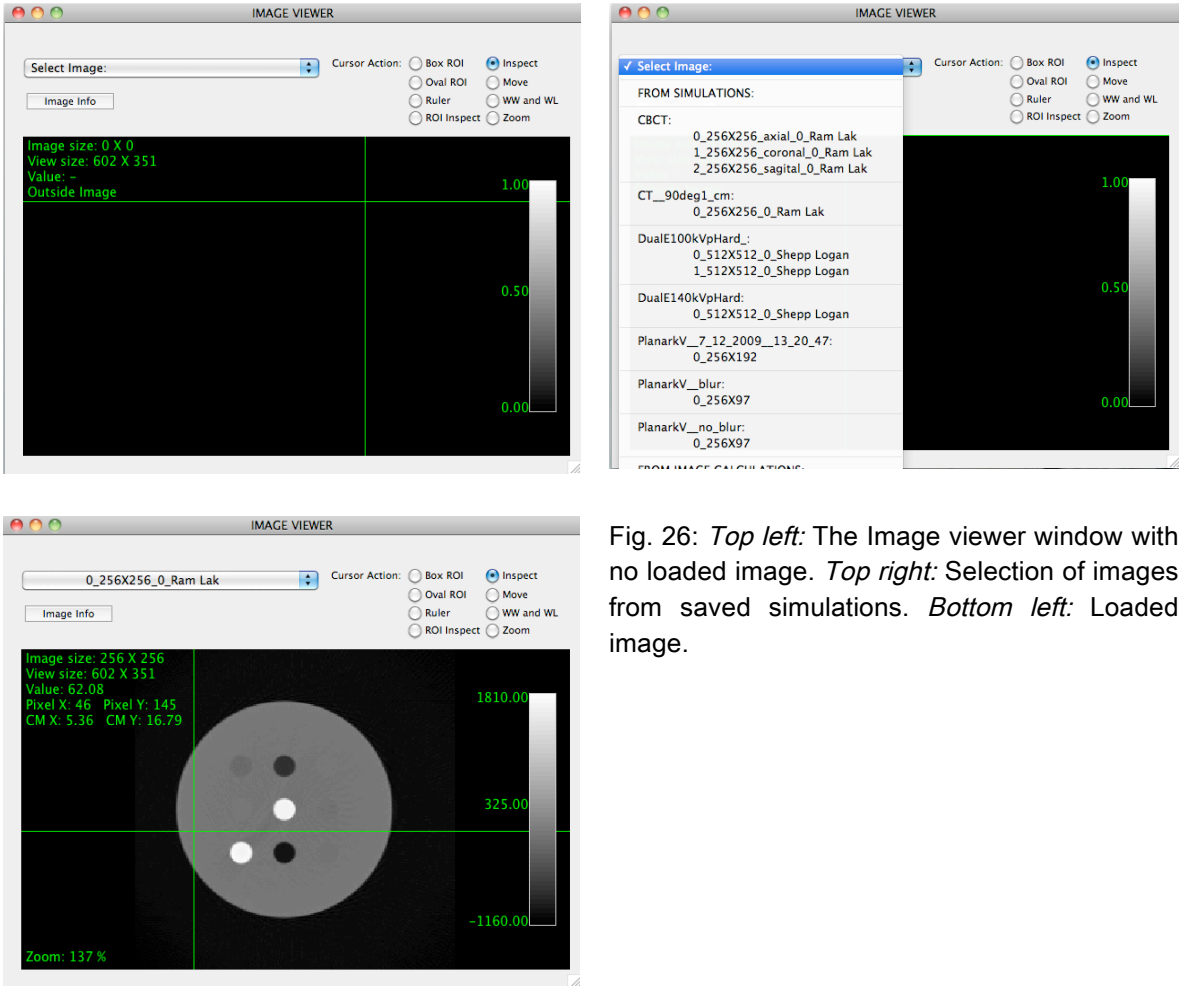

Fig. 26: *Top left:* The Image viewer window with no loaded image. *Top right:* Selection of images from saved simulations. *Bottom left:* Loaded image.

As seen from figure 26, to load an image, the user presses the **Select Image** drop down menu. This menu shows available images grouped by simulations. Clicking on an image will load it into the viewer. At this point the user

can move the cursor to inspect values in the image. The cursor can be made to do the following:

- Draw a rectangular ROI
- Draw an oval ROI
- Draw line ROI/Ruler
- Inspect ROIs (select them, move them, no resizing)
- Inspect (default, simple cross hair to inspect image values)
- Move the image
- Window width and level (dragging vertically/horizontally)
- Zoom in and out

Pressing the Image Info button will yield information on the image. This information is a summary. It simply states which inputs were used to generate the simulation.

When using ROIs, whether line, oval or rectangular, pressing Enter when an ROI is selected will open a line profile in case of a line ROI and an histogram in the case of the oval or rectangular ROIs. Moving the ROI with the ROI select cursor will update the plots. See figure 27.

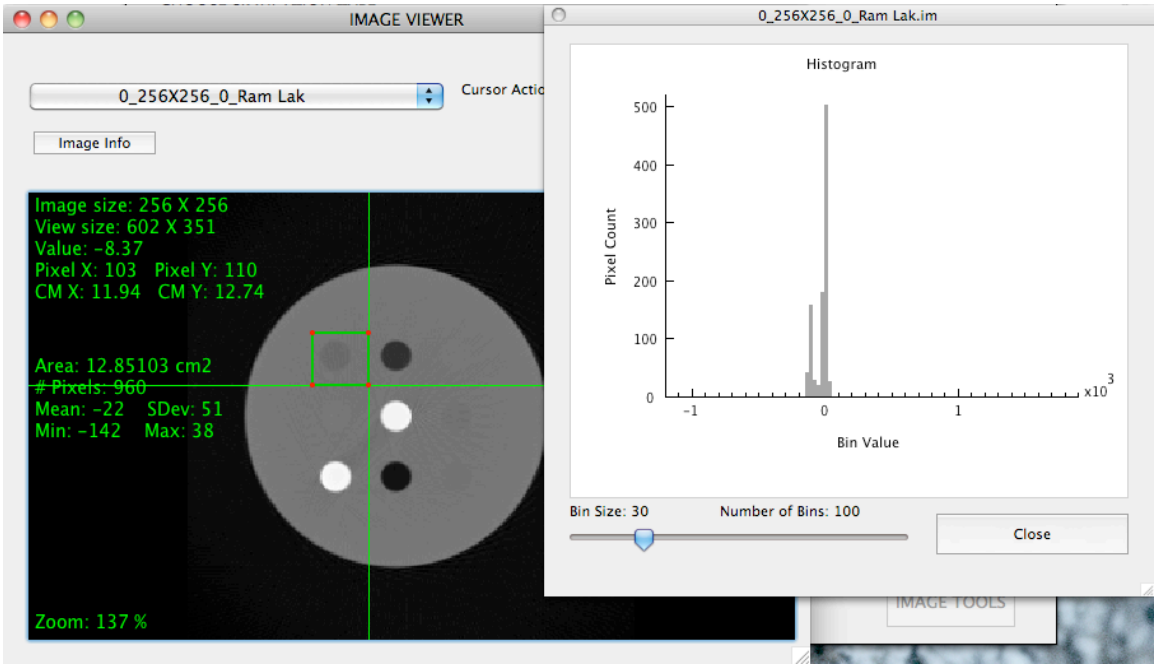

Fig. 27: A histogram associated with a rectangular ROI.

The histogram or line profiles can also be opened by going in the **Image Options** menu **-> ROIS -> Histogram/Profile**. Other options of this menu include **Delete All ROIS** or **Delete ROI**.

The **Image Options** menu also contains a color scale menu where the user can pick amongst a series of color scales or invert the current color scale. From the **Image Options** menu it is also possible to manually modify window and level.

The **Math** menu lets the user launch the **MATH** window by pressing on the **Image Operations...** menu item. Operations are listed below:

- Sum of two images
- Difference of two images
- Product of two images
- Quotient of two images
- Normalization of a single image
- Background subtraction of single image
- Re-grid single image with nearest neighbour interpolation

- Re-grid single image with bilinear interpolation
- Gamma comparison of two images in 2D

Figure 28 shows the **MATH** window. When opened with an image loaded in the image viewer, the **MATH** window always selects this image as first image. It is possible to change this by using the first drop down menu. Once the image is selected, the second drop down menu is used to select an image operation. Depending on the operation, a second image might need to be selected with the third drop down menu.

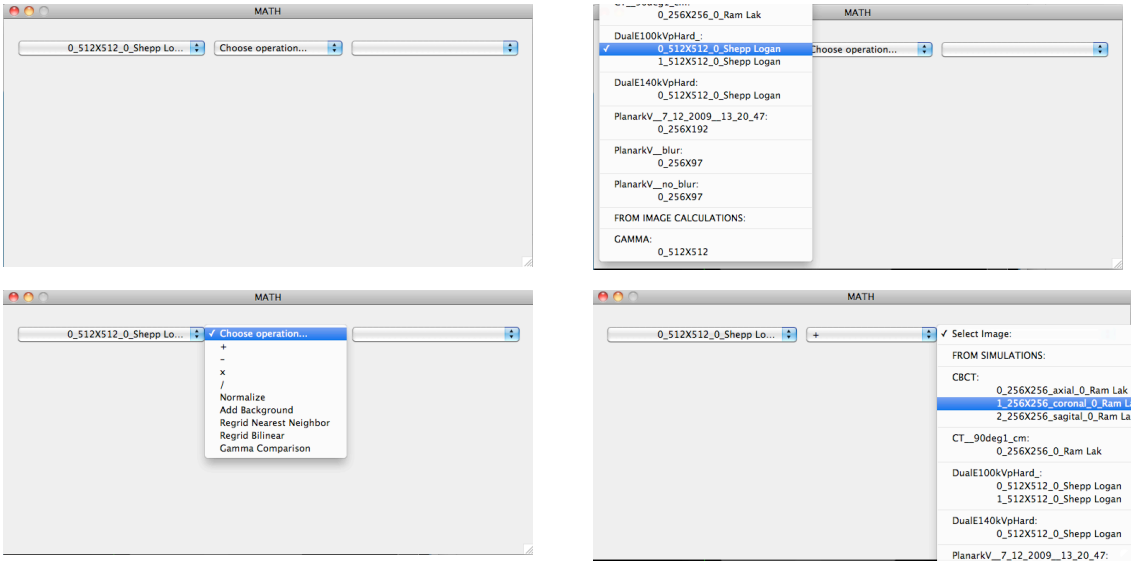

Fig. 28: The steps involved in doing image operations.

When doing arithmetical operations such as +, -, x, /, the user must specify a final image size. This image size is the size of the output of the calculation. Before image size is specified, the software has determined the area of overlap between the images. The final image will have the aspect ratio of this area. When giving an image size, the user specifies only one size (first one), the second one is handled by the software to provide isotropic resolution. If resolution of the final image does not match the one of the initial images, bilinear interpolation is used.

7.1 Gamma comparison

The algorithm used to calculate gamma comparisons is described in details in the physics manual.

The following figure shows the parameters the user must input in the MATH window.

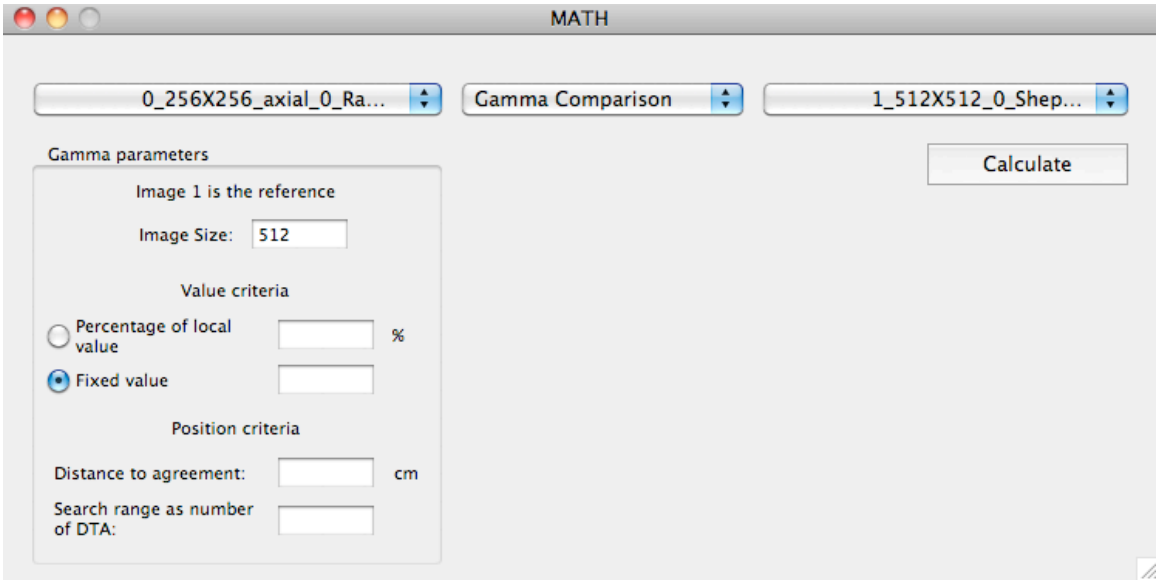

Fig. 29: Gamma comparison.

The user first specifies the output image size (larger takes longer). He then decides whether the comparison uses a percentage of the local value in the reference image or a global value for ΔD (**Value criteria**). Next the distance to agreement must be given, as well as the number of DTA to search in (**Position criteria**).

The gamma image will be shown with a color scale which is blue to green from 0 to 1, and yellow to red from 1 to MAX, as shown in figure 30.

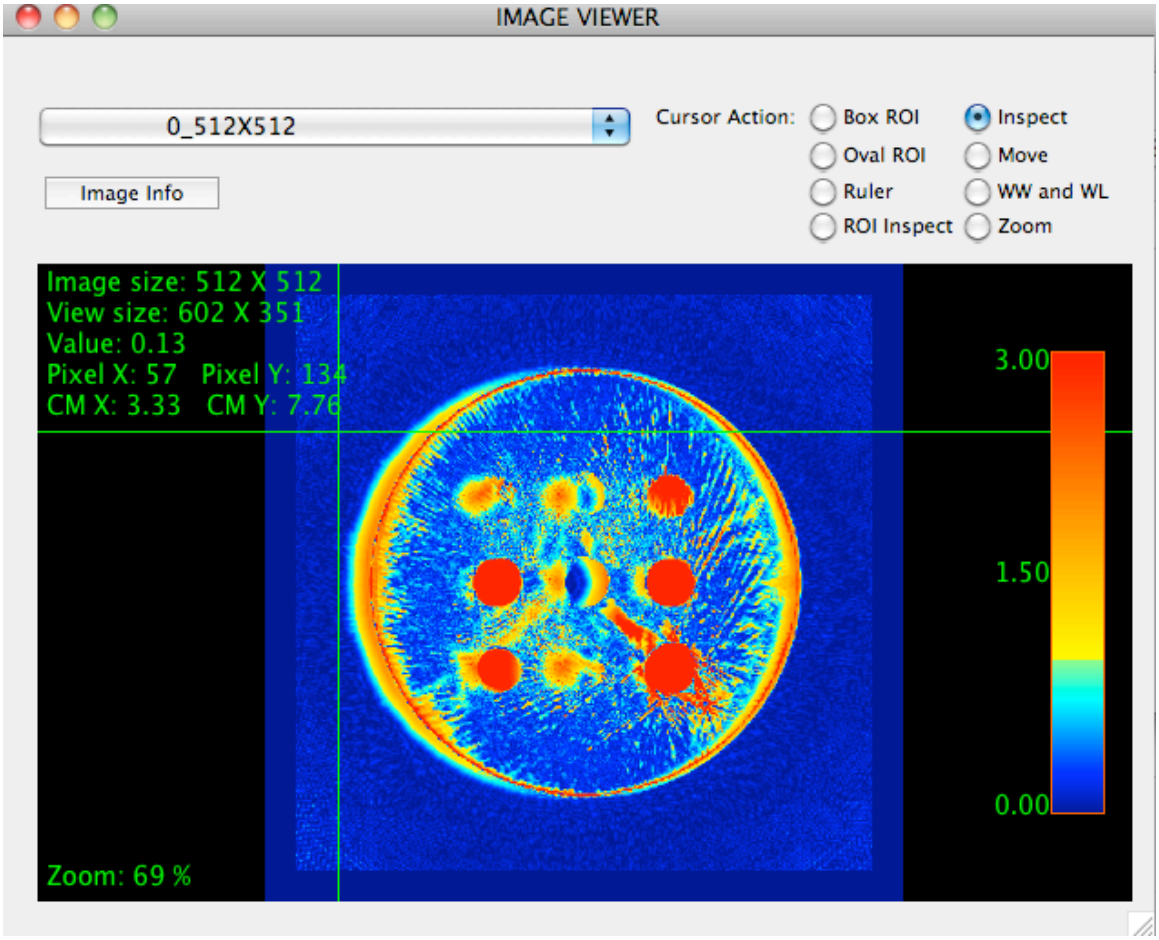

Fig. 30: A gamma comparison image with dual color scale. The second image studied was shifted and rotated from the orginal.

APPENDIX A – DETECTOR ENERGY RESPONSES

Energy responses in *ImaSim* are read from data files. Each response has an associated data file. They are found in the **.../ImaSim/Detectors** folder under OSX and in the **\ImaSim\Detectors** folder under Windows. Detector files have a **.det** extension.

A user can use his own detector response curves in *ImaSim*. He simply needs to place a **.det** file in the **Detectors** folder. The file is of the following format (figure 31):

```
Name: CsI flat panel
Energy(keV) Response (E_abs/E_inc, normalized to max response)
1 0
10 0
11 0.151553
12 0.2388256
13 0.3296951
14 0.4172451
15 0.4972333
16 0.5680158
17 0.6294961
18 0.6794766
19 0.7242826
20 0.7625931
21 0.7935463
22 0.8204639
23 0.8434253
24 0.8574982
25 0.8670212
26 0.8712933
27 0.8732523
28 0.8702737
29 0.8631418
30 0.8488009
31 0.8340923
32 0.816278
33 0.7984196
34 0.9405576
35 0.9724868
36 0.9778098
37 0.987506
38 0.9907677
39 0.9941925
40 0.9966952
41 0.99897
42 1
```

Fig. 31: File format for .det files.

The name used by *ImaSim* will actually be the file name without the extension. The content of the first two lines of the file is not important. It is there to facilitate user comprehension. Although their content is not important, the lines themselves should be there, even if empty. The data starts on the third line and

is energy in keV followed by a separator (white space) followed by the fraction of energy absorbed by the detector at that specific photon energy. The data has to be normalized so the maximum absorbed fraction is unity.

The data does not have to be a on a regular energy grid. Linear interpolation will be used between data points when needed by the software. It is recommended to provide data beyond the maximum energy to be used with the detector.

APPENDIX B – MEGAVOLTAGE PHOTON SPECTRA

MV spectra in *ImaSim* are read from data files. Each spectra has an associated data file. They are found in the **.../ImaSim/MV Spectra** folder under OSX and in the **\ImaSim\MV Spectra** folder under Windows. Detector files have a **.spec** extension.

A user can use his own MV spectra in *ImaSim*. He simply needs to place a **.spec** file in the **MV Spectra** folder. The file is of the format shown in figure 32.

```
**** COMMENT ****

**** INPUTS ****
kVp [kV] hvMIN [keV] Dhv [keV]
4000  250  250
Angle [deg.]
0
t_AIR t_BE t_AL t_CU t_SN t_W t_Wa [mm]
1000  0  0  0  0  0  0
Nf P
1  0
alpha [deg.] Y [mm] H [mm]
0  0  1000
****CALCULATED OUTPUTS ****
Brem[uGy/mAs@1m] Char[uGy/mAs@1m]
0  0
HVL1[cm AL] HVL2[cm AL] HVL1[cmCu] HVL2[cmCu] MeanE[keV] EffEAl[keV] EffECu[keV]
0  0  0  0  0  0  0
**** CALCULATED SPECTRUM ****
Energy[keV]  N[keV cm^2 mAs]^-1 @ 1 meter
250  0.0111
500  18.11
750  72.09
1000  54.08
1250  53.57
1500  56.33
1750  34.69
2000  26.21
2250  24.91
2500  16.97
2750  13.99
3000  7.035
3250  8.833
3500  8.809
3750  8.838
4000  0.9982
```

Fig. 32: File format for .spec files.

This file format can seem cryptic for MV spectra. The file format is also shared by kV spectra produced by the **Source Editor**. Some of the parameters in the file are thus useless for MV spectra. To create a new spectrum, the file below should be copied as is. What needs to be changed is **kVp**, **hvMIN**, **Dhv** and the actual spectrum values. The first input, **kVp**, has to correspond to the peak energy of the spectrum in keV. Followed by a space is the smallest energy value in the spectrum (**hvMIN)** , then the width between energy values (**Dhv)**. The values of the spectrum need to be on a regular grid. The spectrum will be used in a relative fashion, meaning that the units of number of photons are not important.

APPENDIX C – LOADING SAVED DATA IN MATLAB

In the saved simulations folder, located in the main ImaSim folder, a .m file can be found which will load saved ImaSim data into matlab. Running the code in the .m file will prompt you to select a folder where a simulation has been saved and will load available data in matlab.

APPENDIX D – GENERATING NEW MATERIALS

Material data (attenuation) is loaded from individual material files located in the **.../ImaSim/ Attenuation_Coeff** folder under OSX and in the **\ImaSim\ Attenuation_Coeff** folder under Windows. The files have .mat extension. To generate attenuation data for new materials, the XCOM database from the NIST is used (http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html). An example is displayed in figure 33 for PMMA. We recommend setting the maximum energy to 6 MeV as ImaSim does now have higher energy spectra.

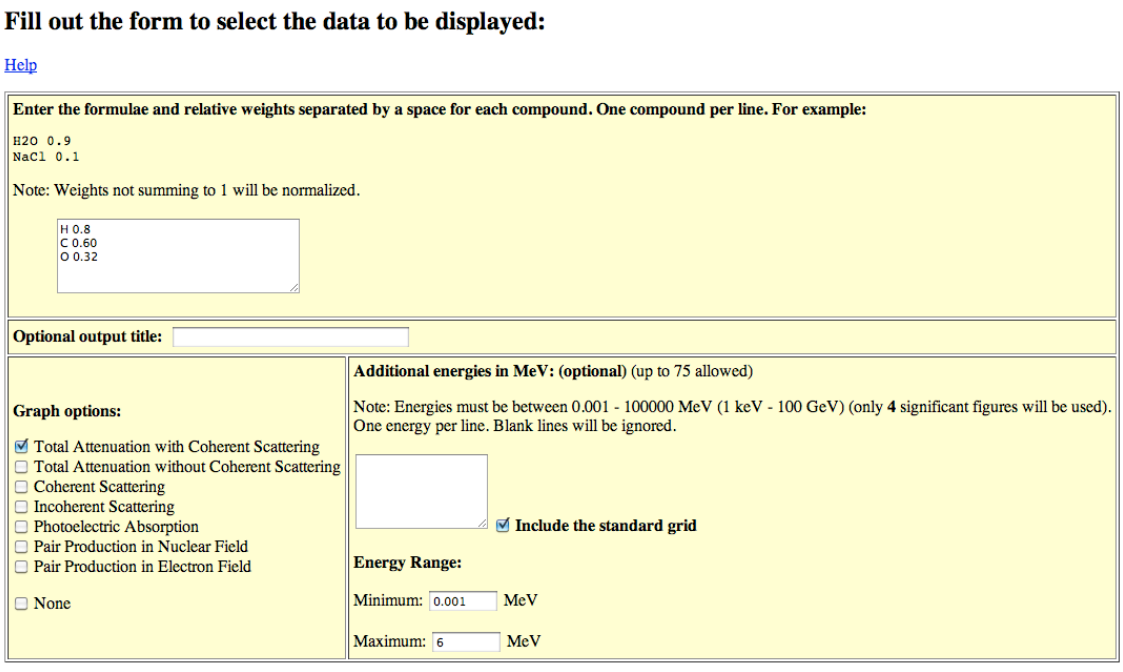

Fig. 33: Example input for PMMA on the mixture section of the XCOM database.

After pressing **submit information,** you must check boxes for each column and download the data with spaces as separator, see figure 34.

Constituents (Atomic Number : Fraction by Weight)

```
Z=1     : 0.465116
Z=6     : 0.348837
Z=8     : 0.186047
```

To download data in spreadsheet (array) form, choose a delimiter and use the checkboxes in the table heading. After downlc

Delimiter:

- (•) space
- ( ) | (vertical bar)
- ( ) tab
- ( ) newline

Download data | Reset

Edge	(required) Photon Energy	Scattering		☑ Photoelectric Absorption	Pair Production		Total Attenuation	
		☑ Coherent	☑ Incoherent		☑ In Nuclear Field	☑ In Electron Field	☑ With Coherent Scattering	☑ Without Coherent Scattering
	MeV	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g
	1.000E-03	8.170E-01	2.940E-02	1.628E+03	0.000E+00	0.000E+00	1.628E+03	1.628E+03
	1.500E-03	7.319E-01	5.789E-02	5.327E+02	0.000E+00	0.000E+00	5.335E+02	5.327E+02
	2.000E-03	6.403E-01	8.763E-02	2.346E+02	0.000E+00	0.000E+00	2.353E+02	2.347E+02
	3.000E-03	4.770E-01	1.380E-01	7.154E+01	0.000E+00	0.000E+00	7.215E+01	7.168E+01
	4.000E-03	3.585E-01	1.726E-01	3.019E+01	0.000E+00	0.000E+00	3.072E+01	3.036E+01
	5.000E-03	2.777E-01	1.951E-01	1.530E+01	0.000E+00	0.000E+00	1.578E+01	1.550E+01

Fig. 34: Example input for PMMA on the mixture section of the XCOM database.

After pressing **Download data,** you can copy paste the whole text output to a new .mat file. Before doing so, you need to add density information (see figure 35) by adding a line with Density, an empty line, the numerical value of density in g/cm3, another empty line then the data from XCOM is pasted.

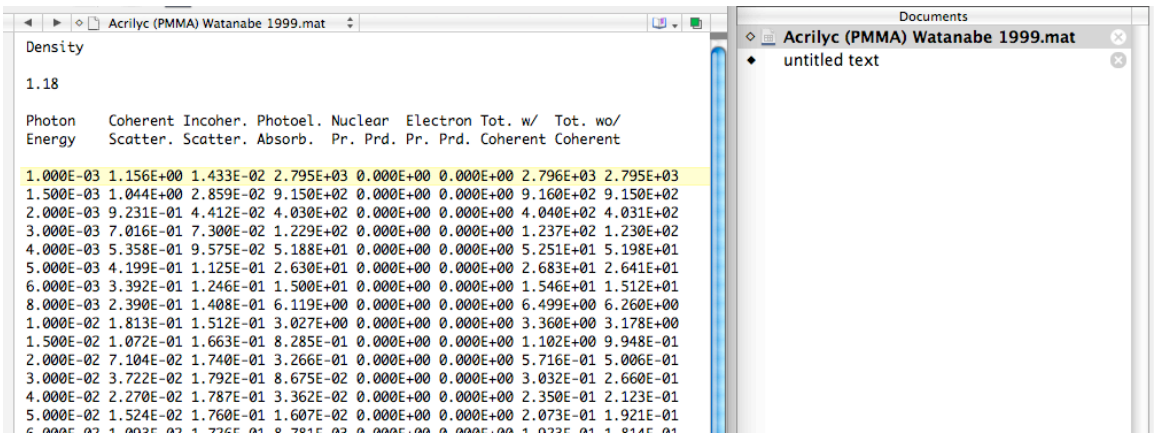

Fig. 35: .mat file format.

WARNING

Adding (or removing) materials to the folder can affect phantoms previously made in ImaSim. When opening the phantom in the object editor, the material names of each component will show up properly, but the file associated to them may be wrong. To correct this problem, the user needs to press **Refresh** in the object editor for each building block of the object. This will refresh the association with data files and correct the problem. The object needs to be saved again.

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