Image-guided therapy and medical robotics tutorial using a LEGO Mindstorms NXT robot and 3D Slicer

Part II: The Basic Tutorial

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Goals of the image-guided therapy and medical robotics tutorial

- To demonstrate the typical steps of an image-guided therapy (IGT) or medical robotics procedure.
- To learn in a hands-on manner using a LEGO Mindstorms NXT, a LEGO phantom and sophisticated medical image processing and IGT software (3D Slicer).

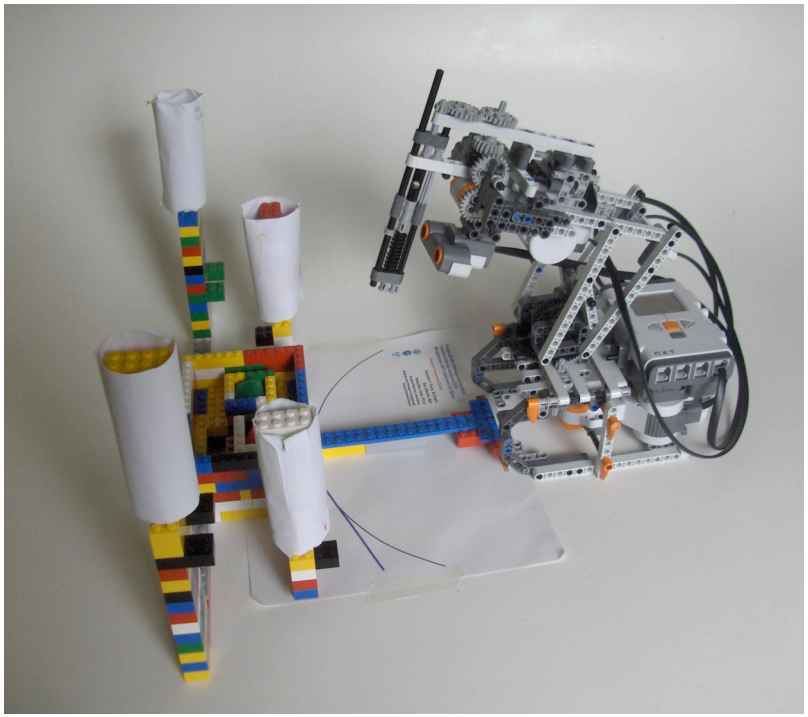
The example procedure that we will use to do this is a needle biopsy.

Goals of the basic tutorial

- To learn about the following steps in IGT and medical robotics in a hands-on manner:
  - ✓ Imaging
  - ✓ Preoperative planning
  - ✓ Targeting and tracking
  - ✓ Navigation

The basic tutorial

In the basic tutorial, the phantom is placed in a predefined position relative to the LEGO robot.

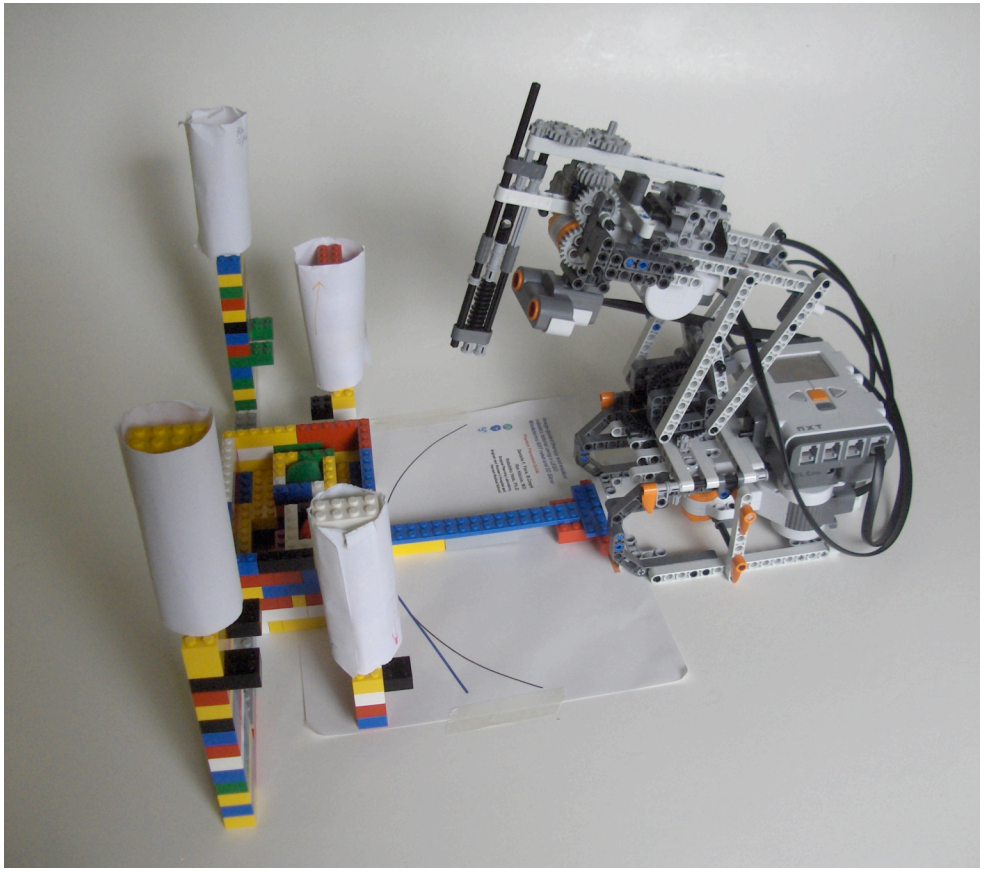


Since the relationship between the phantom and the LEGO robot is known, we can use a predefined registration matrix to transform image coordinates into patient (robot) coordinates.

We do not have to perform registration because it has been done already.

Set up the LEGO robot and the phantom

The final setup:

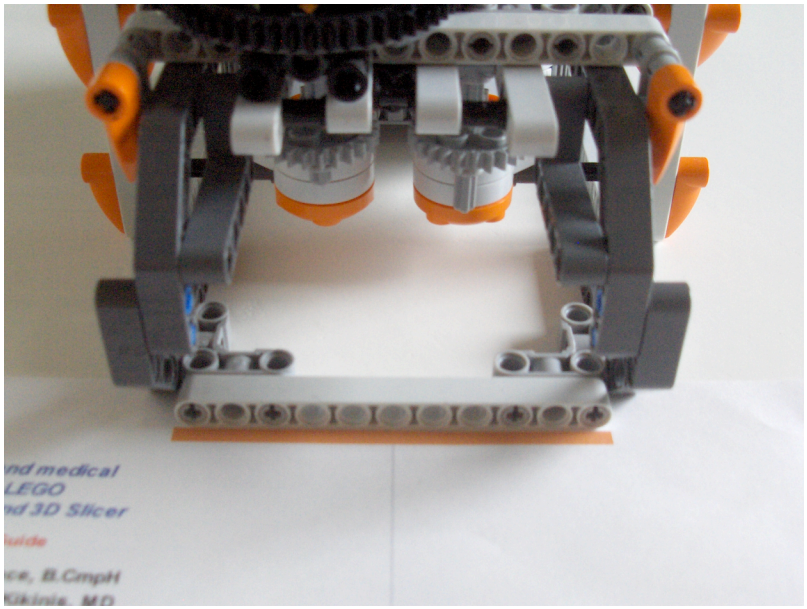


Instructions to follow are in yellow boxes

Set up the LEGO robot and the phantom, continued

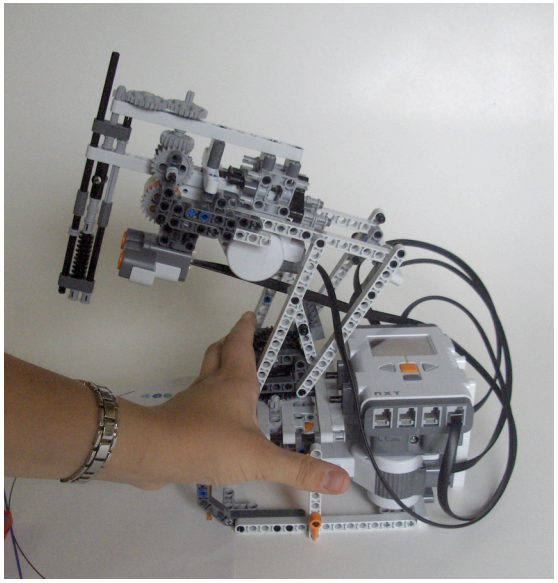
- Tape the phantom placement guide on a table
- Ensure that there is no wall or other object within a four foot radius around the robot, as walls or other objects will interfere with the ultrasonic sensor used in the advanced tutorial
- Remember that you need to use new batteries or a freshly charged battery pack on the robot.

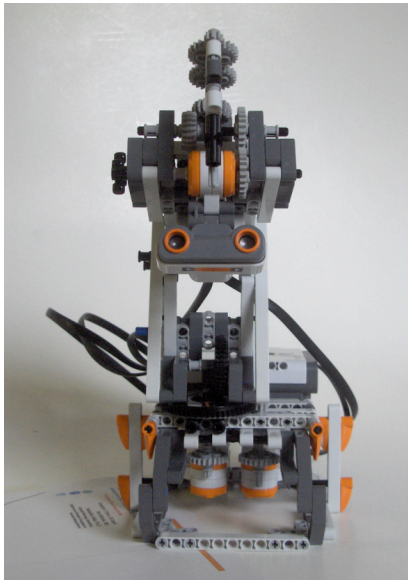
Set up the LEGO robot and the phantom, continued

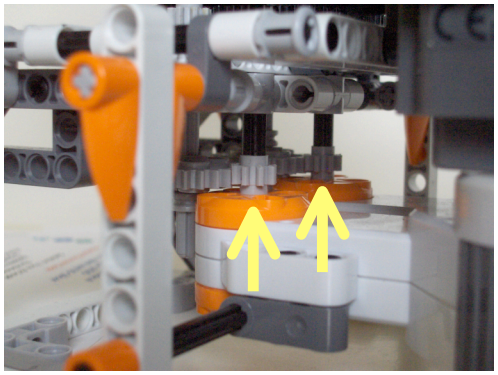


- Position the LEGO robot so that the front piece of the base lines up with the orange line of the phantom placement guide

Set up the LEGO robot and the phantom, continued

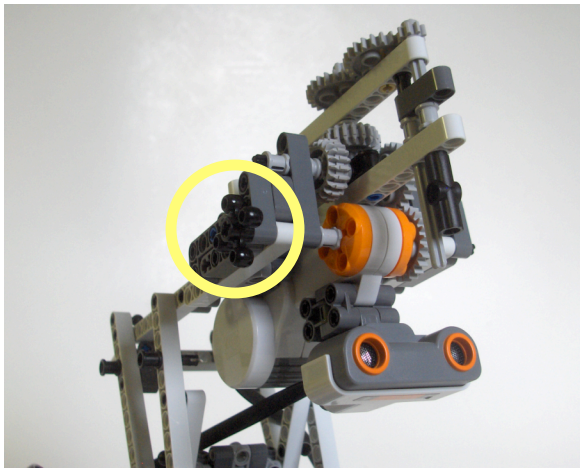


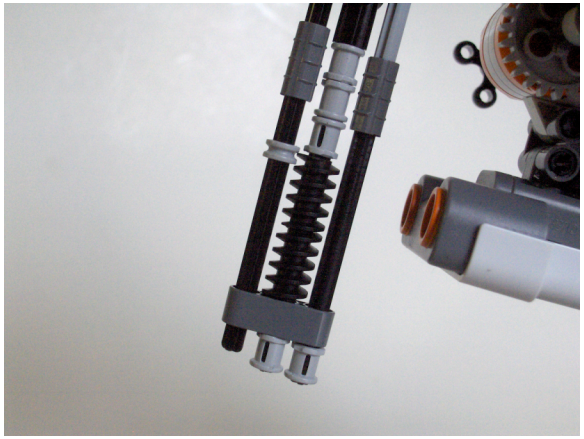




- Position the robot in the "initial position":
  - robotic arm is pushed all the way back
  - robotic arm is centered
- To move the robotic arm:
  - push the small gears at the back of the robot's base **up**
  - Freely move the robotic arm into position
  - Push the small gears at the back of the robot's base back **down** so that they catch on the larger gears

Set up the LEGO robot and the phantom, continued

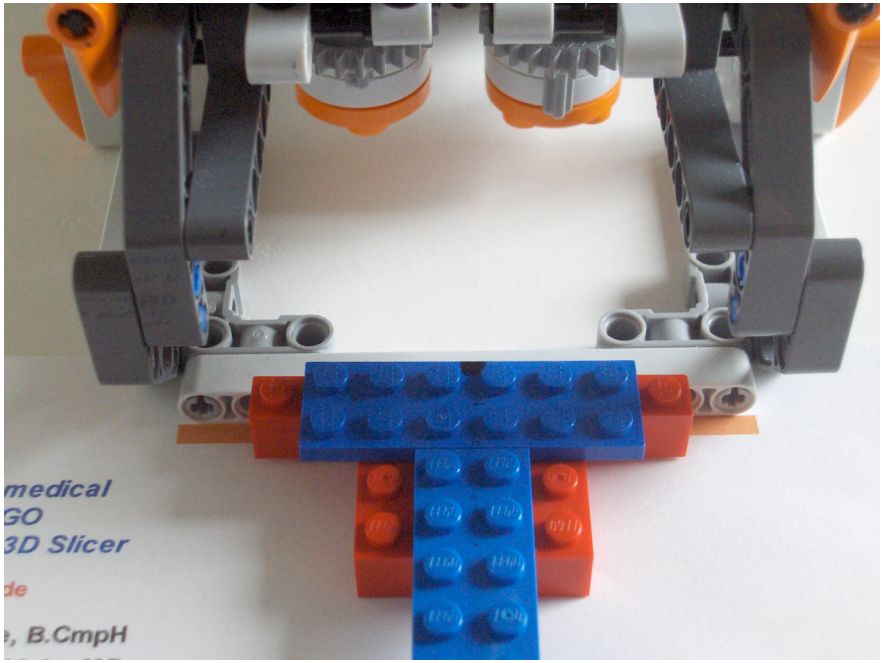




- Using the gear on the upper right side of the robotic arm, adjust the needle so that it is at its highest possible position while still remaining on the thread.

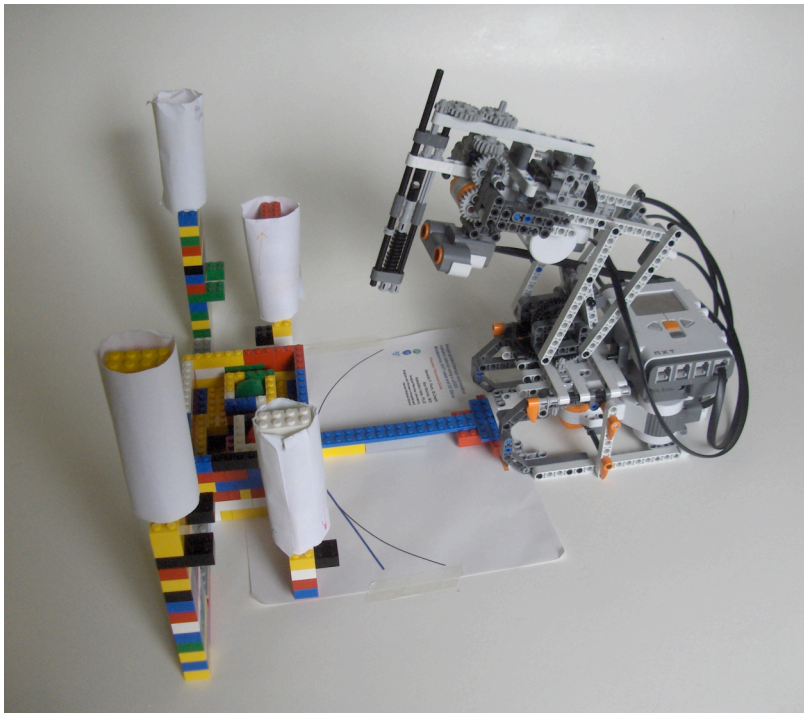
Set up the LEGO robot and the phantom, continued

- Position the phantom so that the bottom spacer is centered on the front piece of the robot's base.



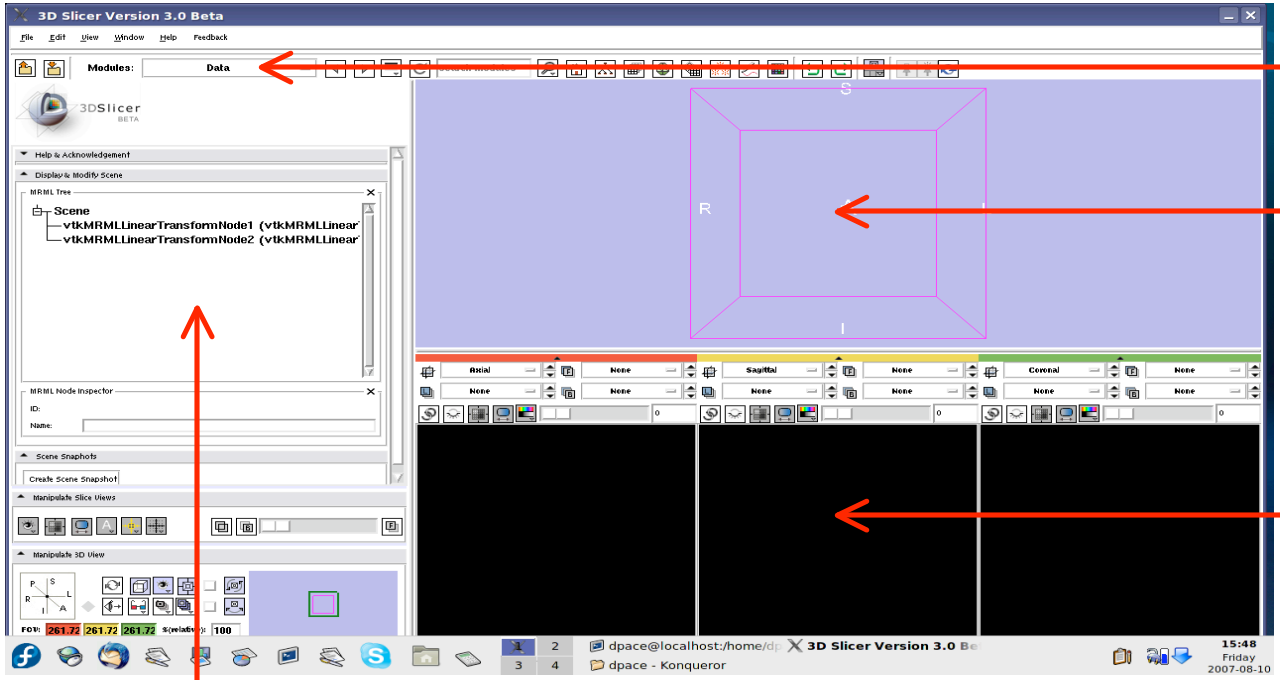
Set up the LEGO robot and the phantom, continued

Your setup should look like this:



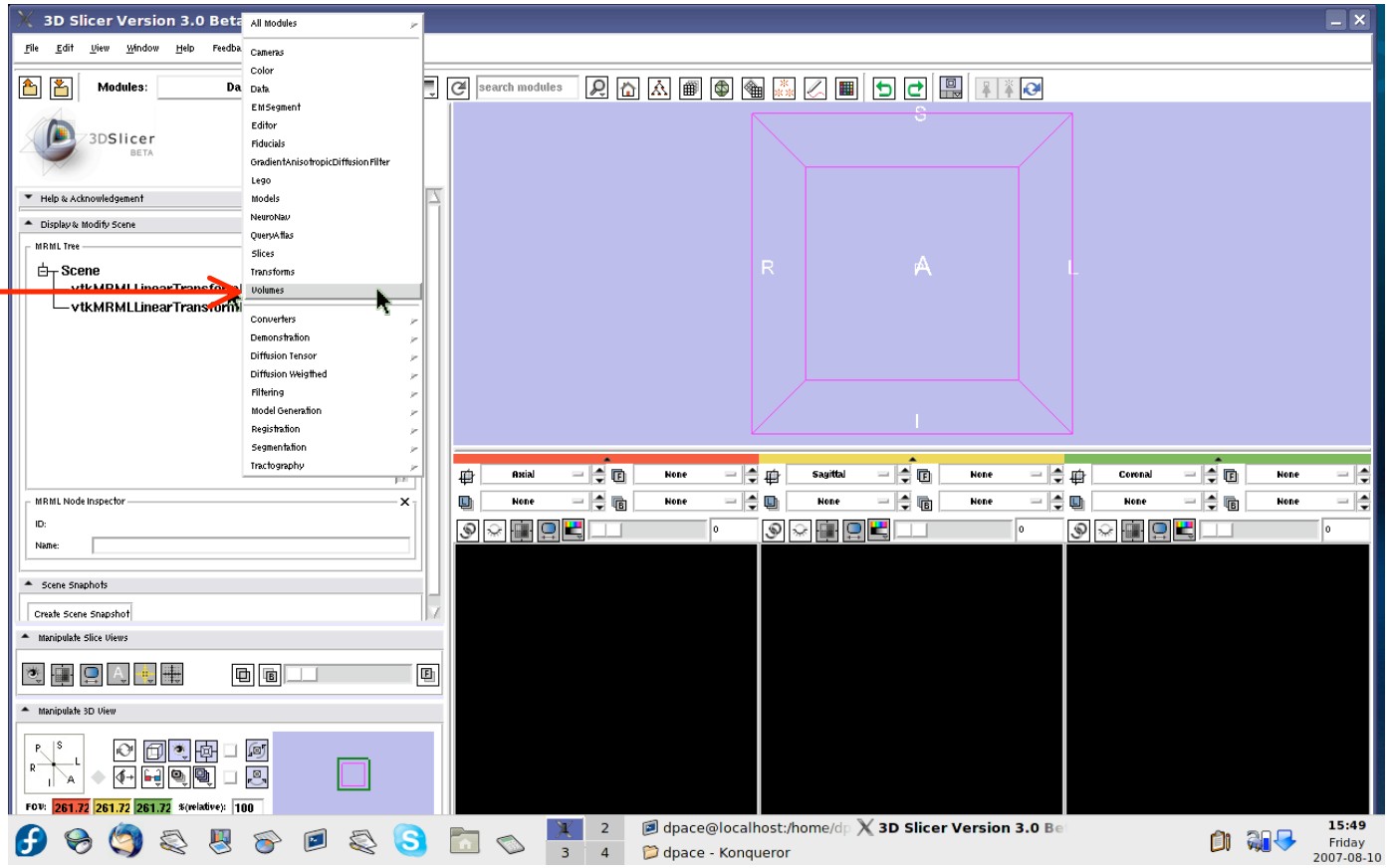
- Connect the robot to the Linux computer using the USB cable provided in the LEGO Mindstorms NXT kit
- Turn the LEGO robot on by pressing the orange button on the NXT brick.

1) Open 3D Slicer



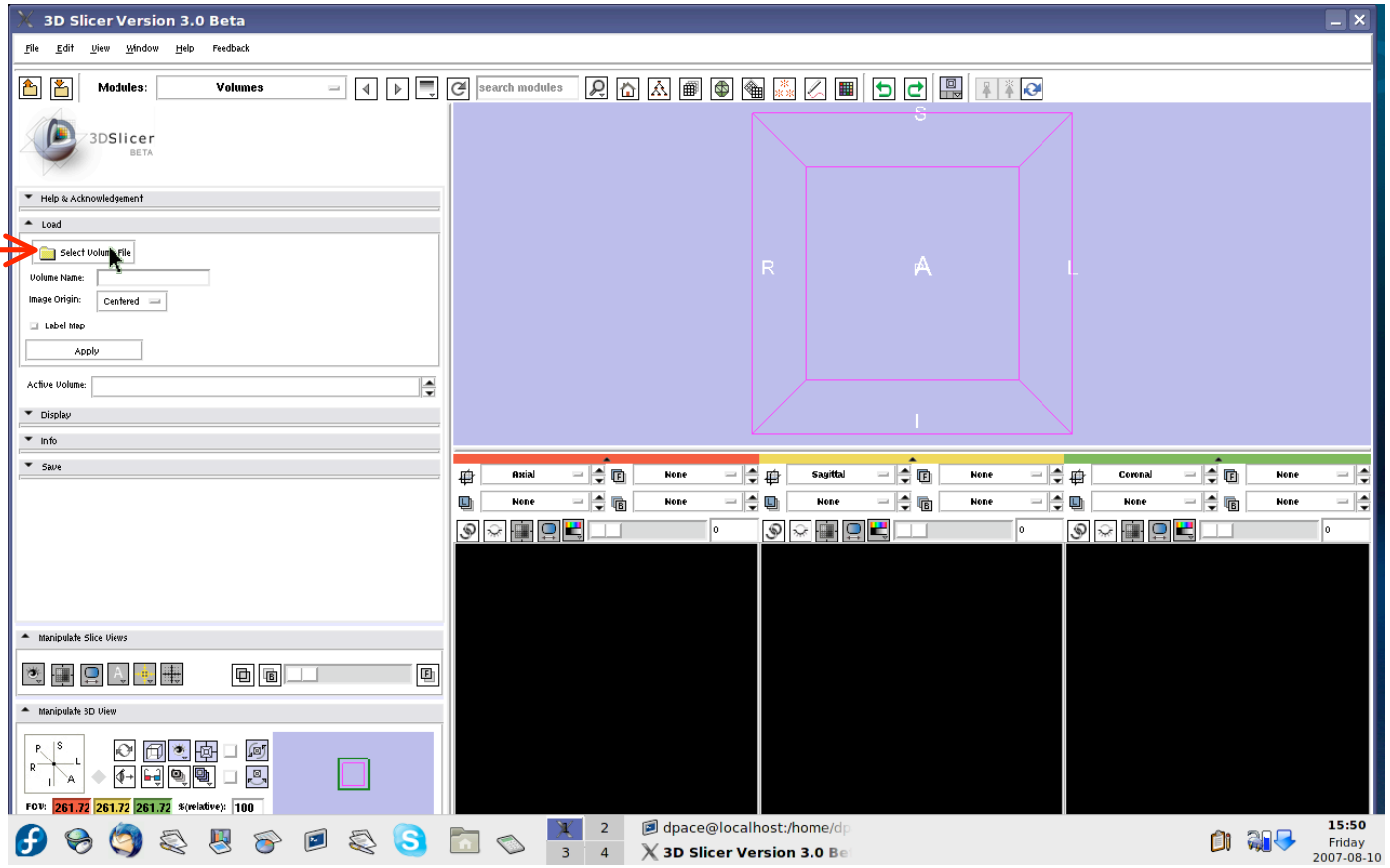
2) Load the CT volume

Open the "Volumes" module



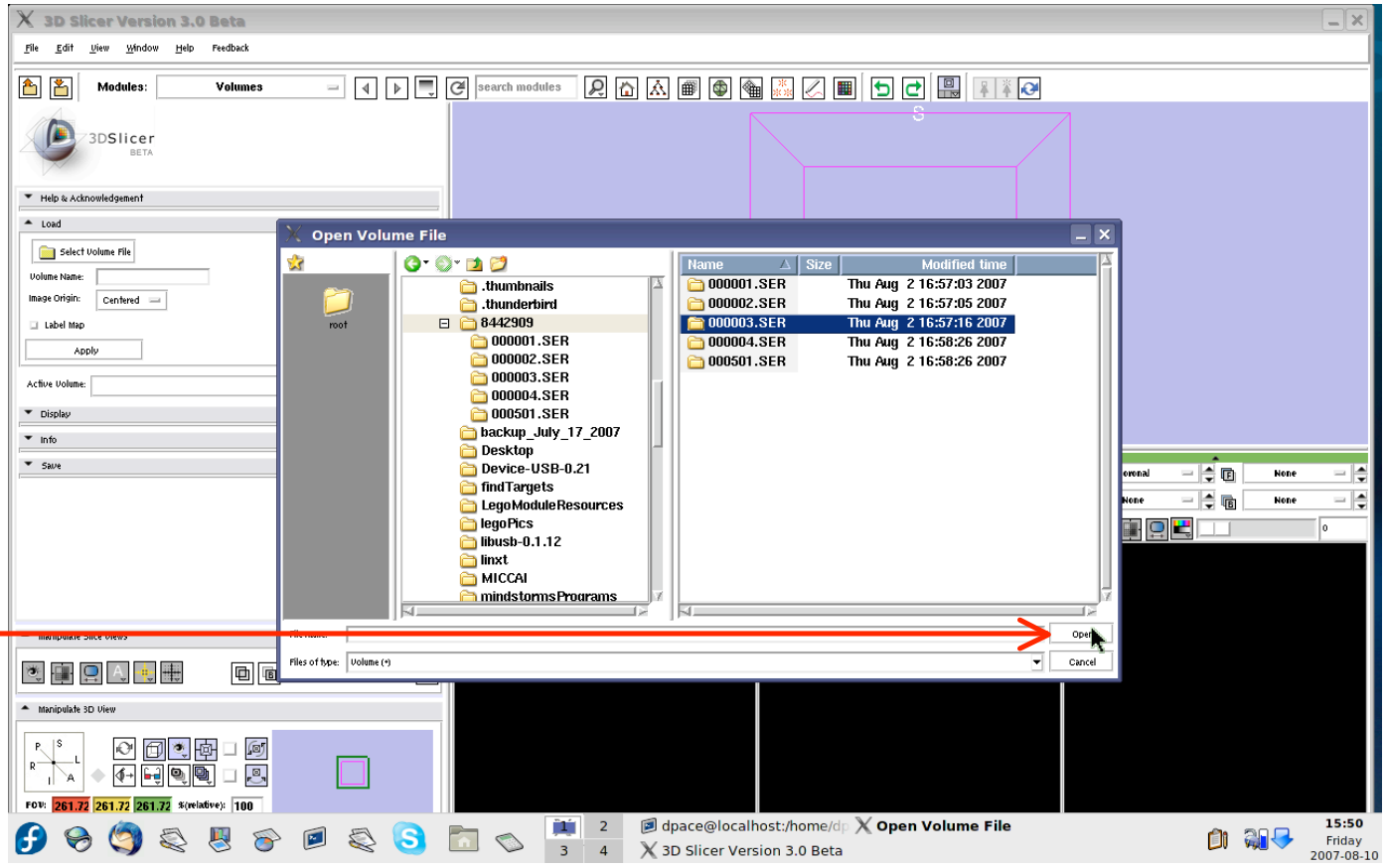
2) Load the CT volume, continued

Click on "Select Volume File"



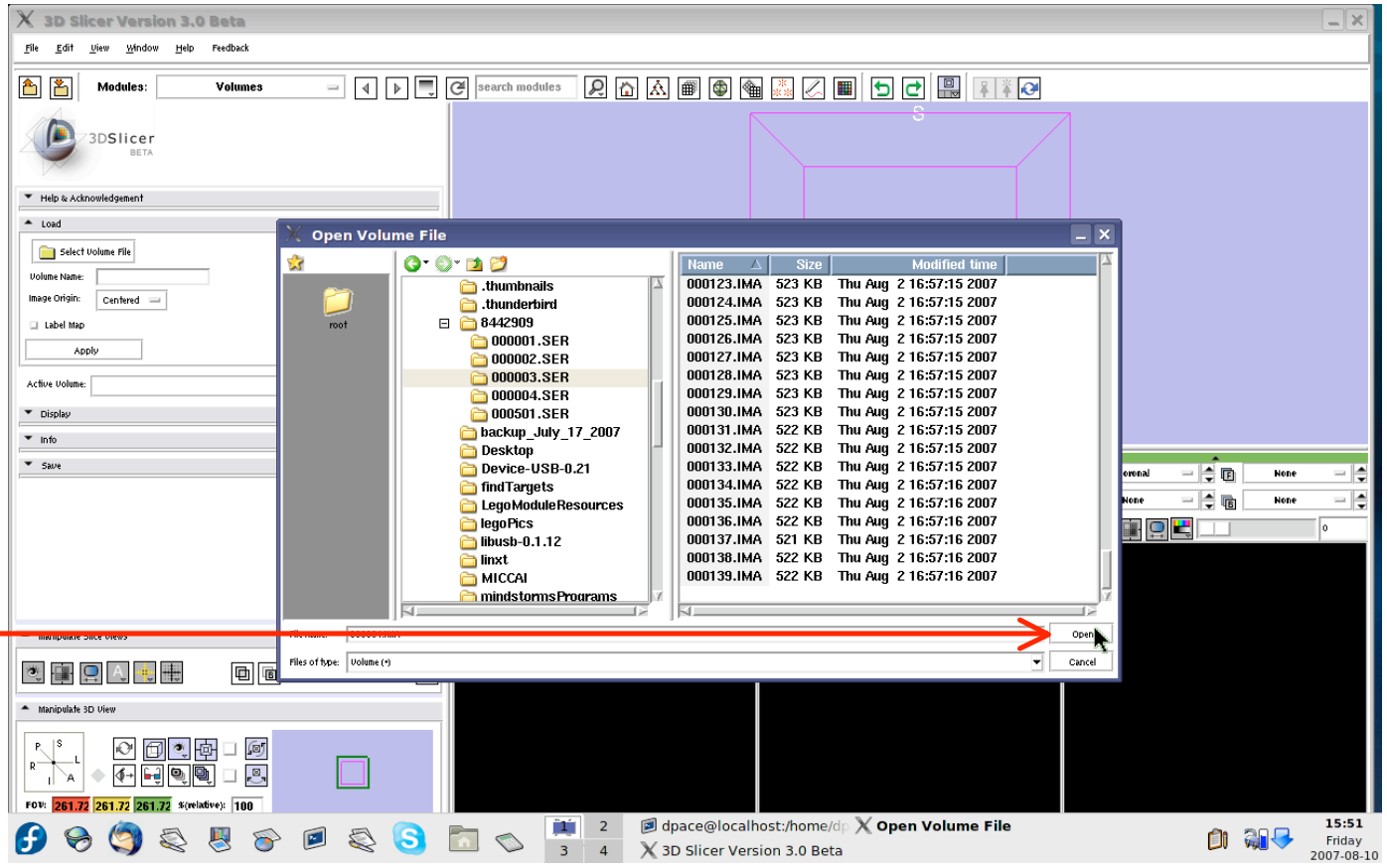
2) Load the CT volume, continued

Click on the folder containing the CT files, then click "Open"



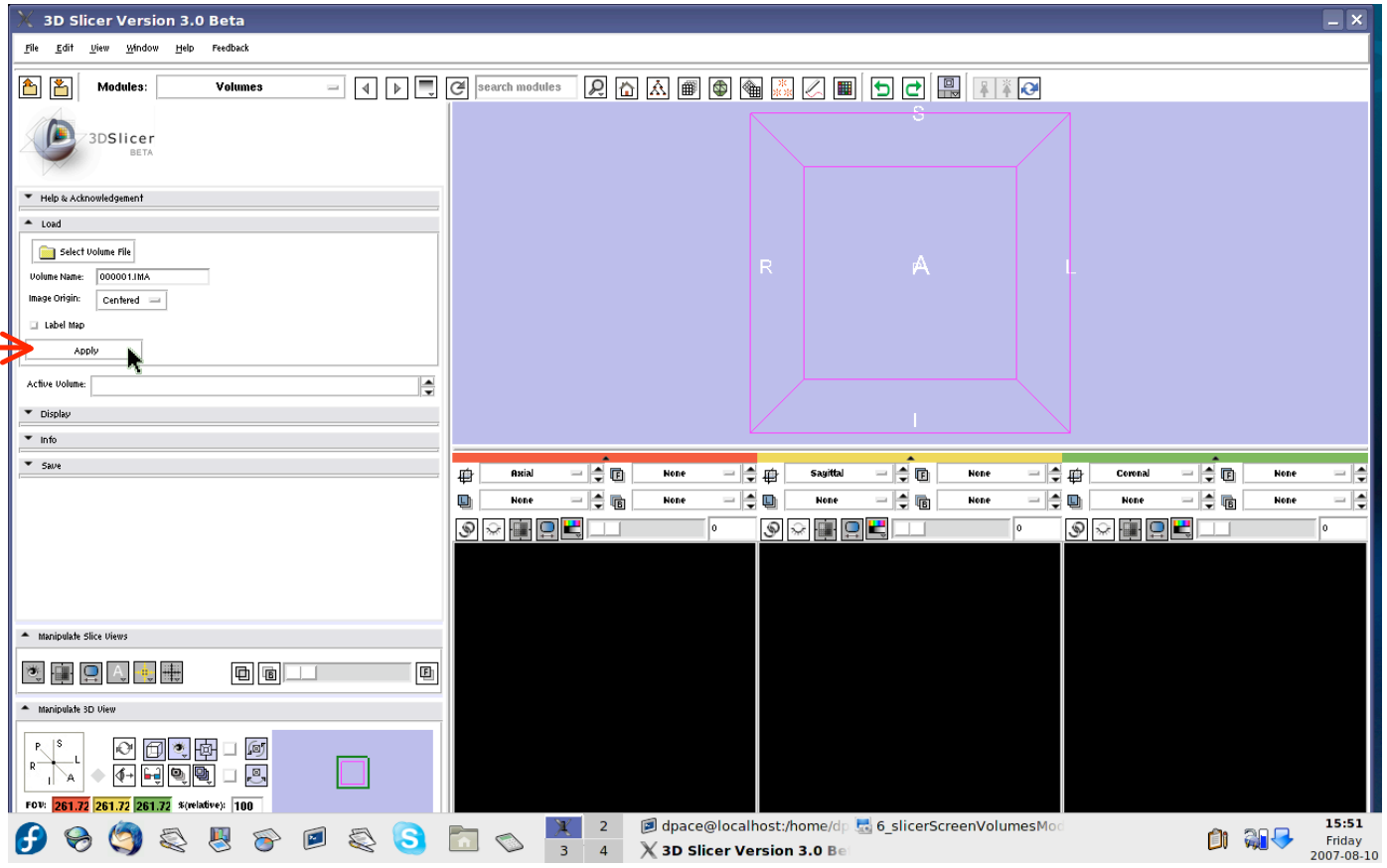
2) Load the CT volume, continued

Click "Open" again

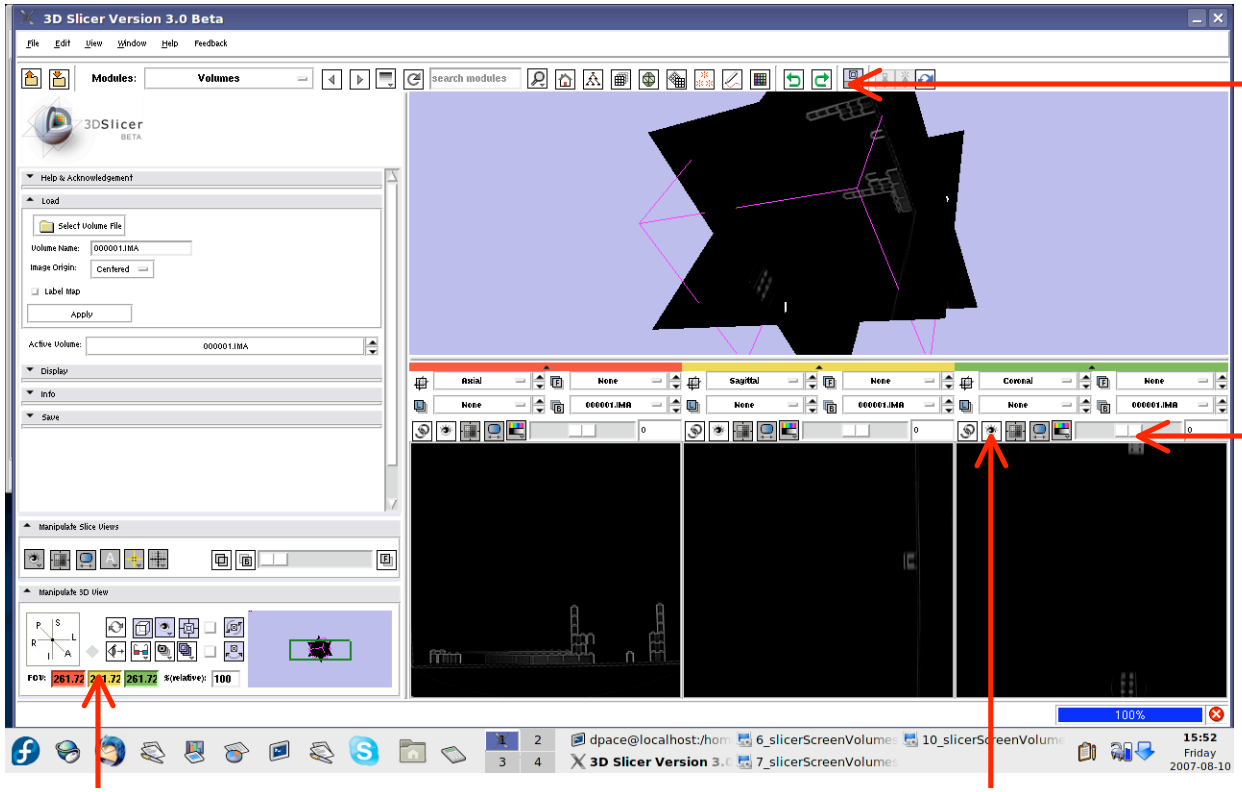


2) Load the CT volume, continued

Click "Apply" and wait until you see the CT volume in the viewers



2) Load the CT volume, continued



You can click here for different layout options for the viewers

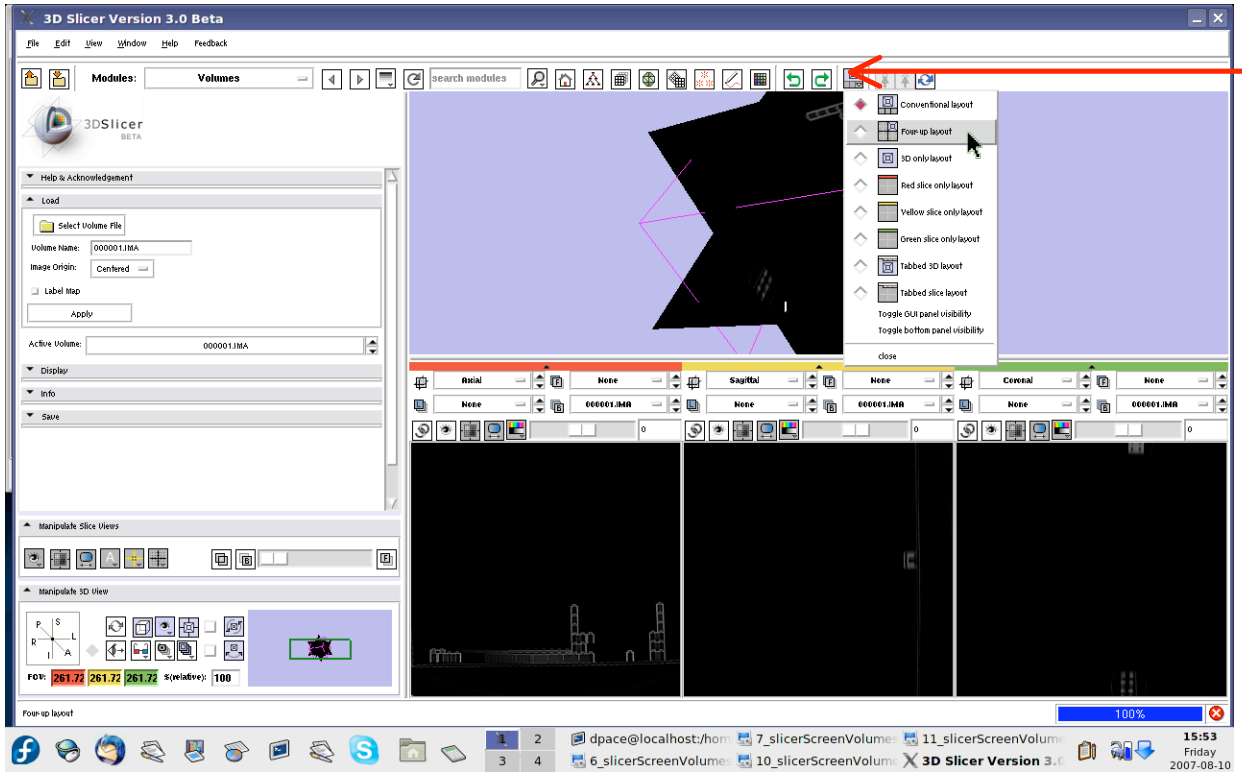
These sliders allow you to scroll through the 2D views of the 3D volume

You can adjust these numbers to change the field of view of the 2D views

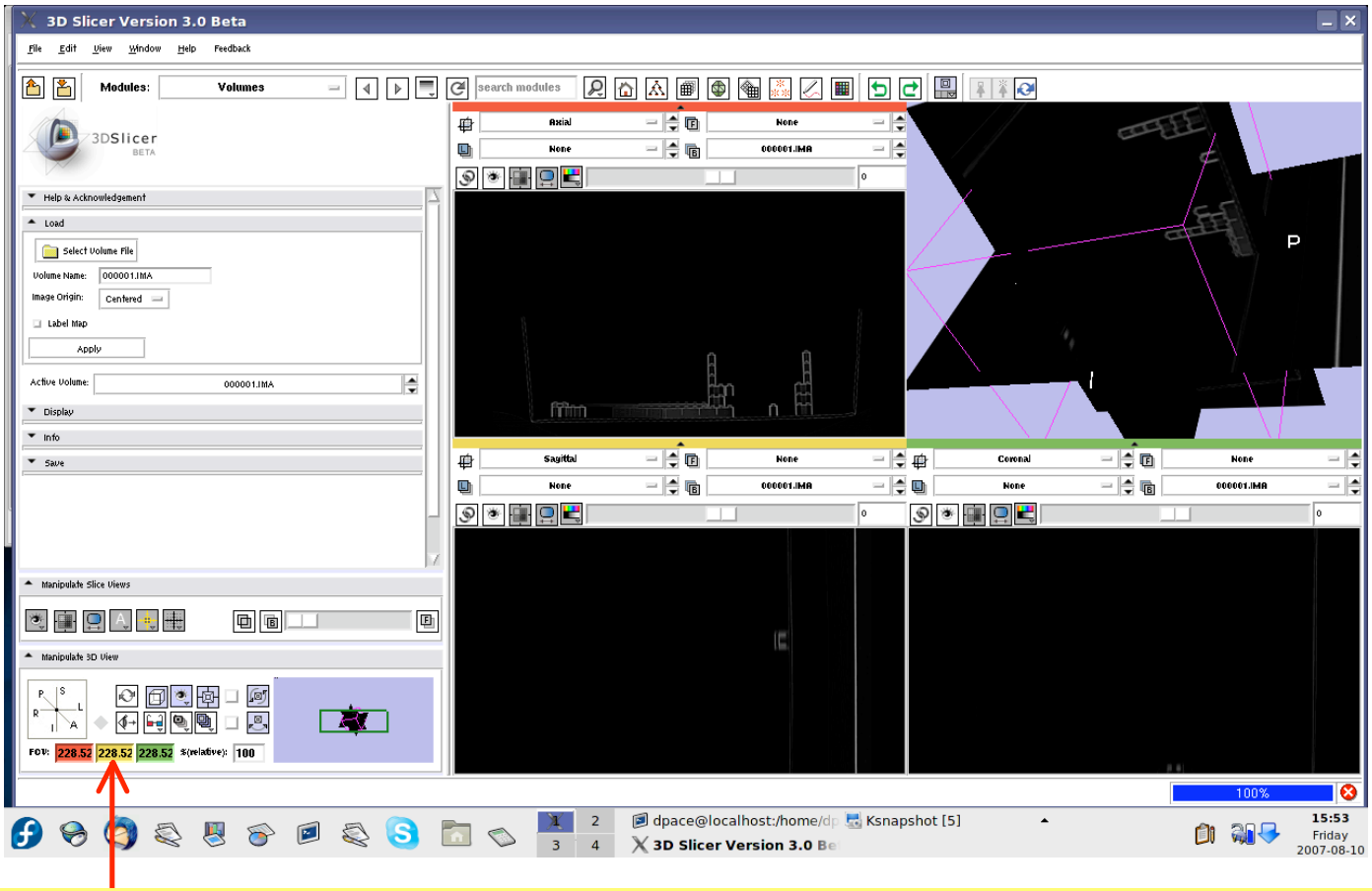
You can click here to make the 2D view visible in the 3D viewer

Click on all three of these buttons

2) Load the CT volume, continued



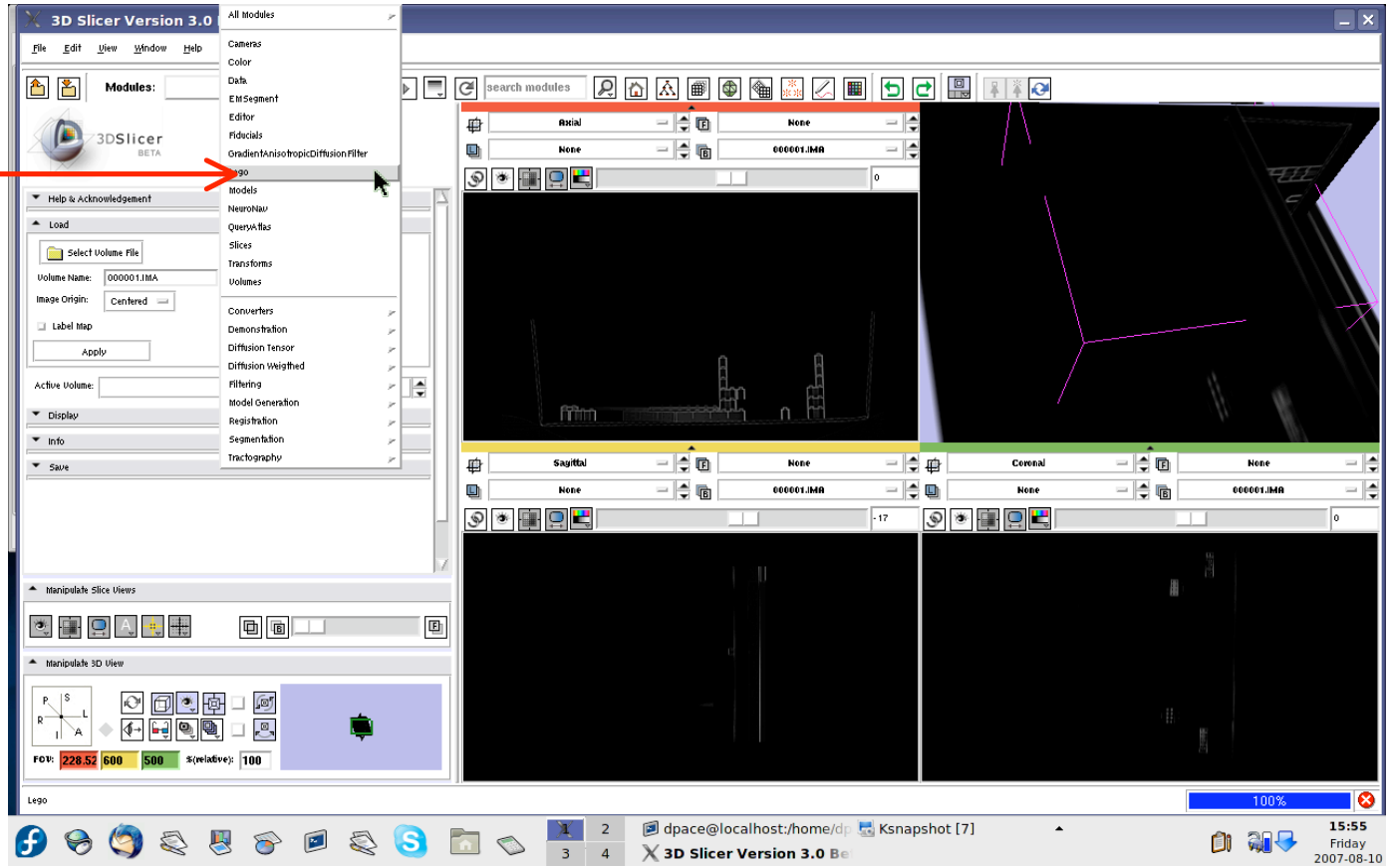
2) Load the CT volume, continued



Adjust the field of view for the axial, sagittal and coronal views so that the entire phantom is visible as you scroll through the slices

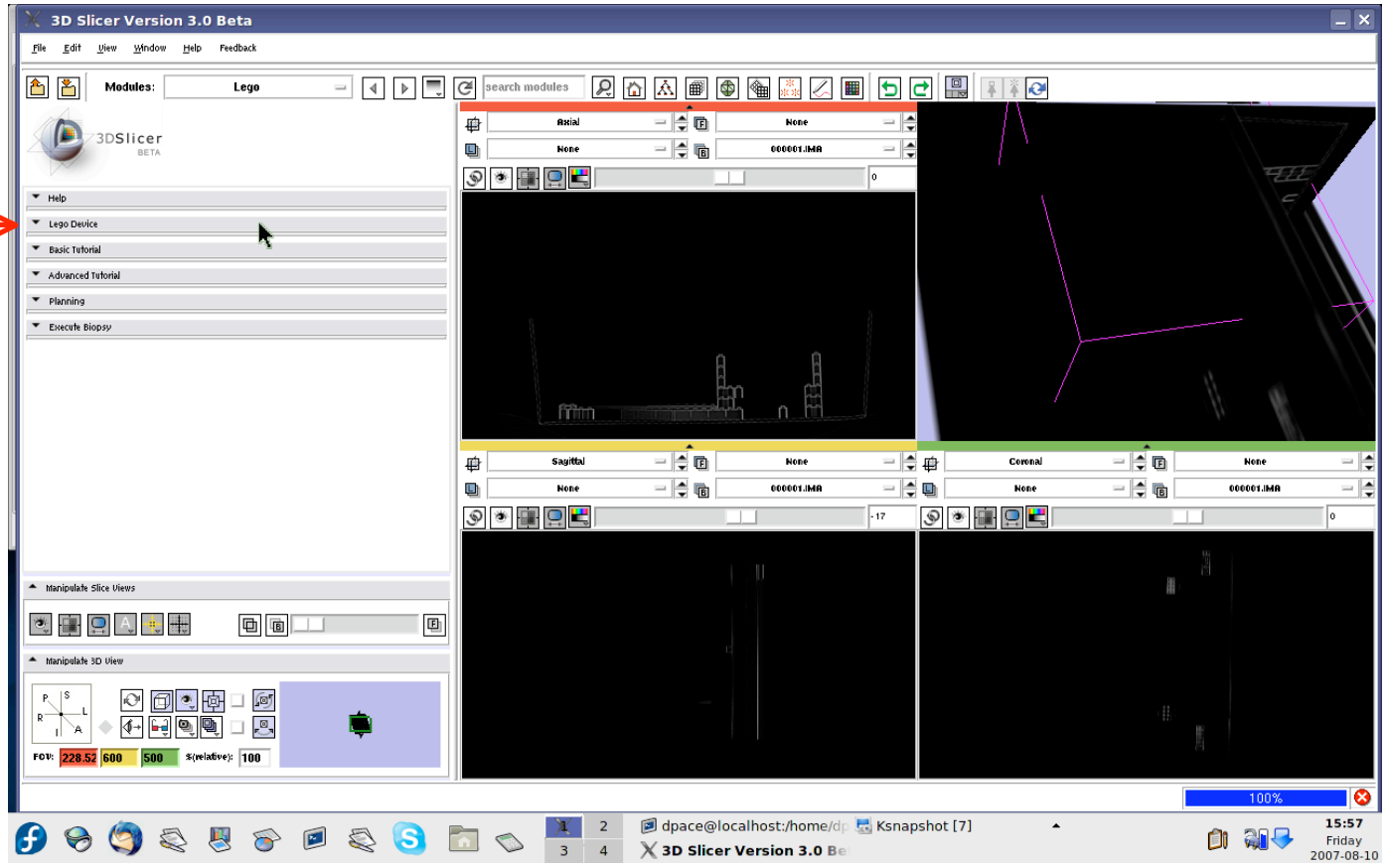
3) Connect to the LEGO robot

Open the "Lego" module



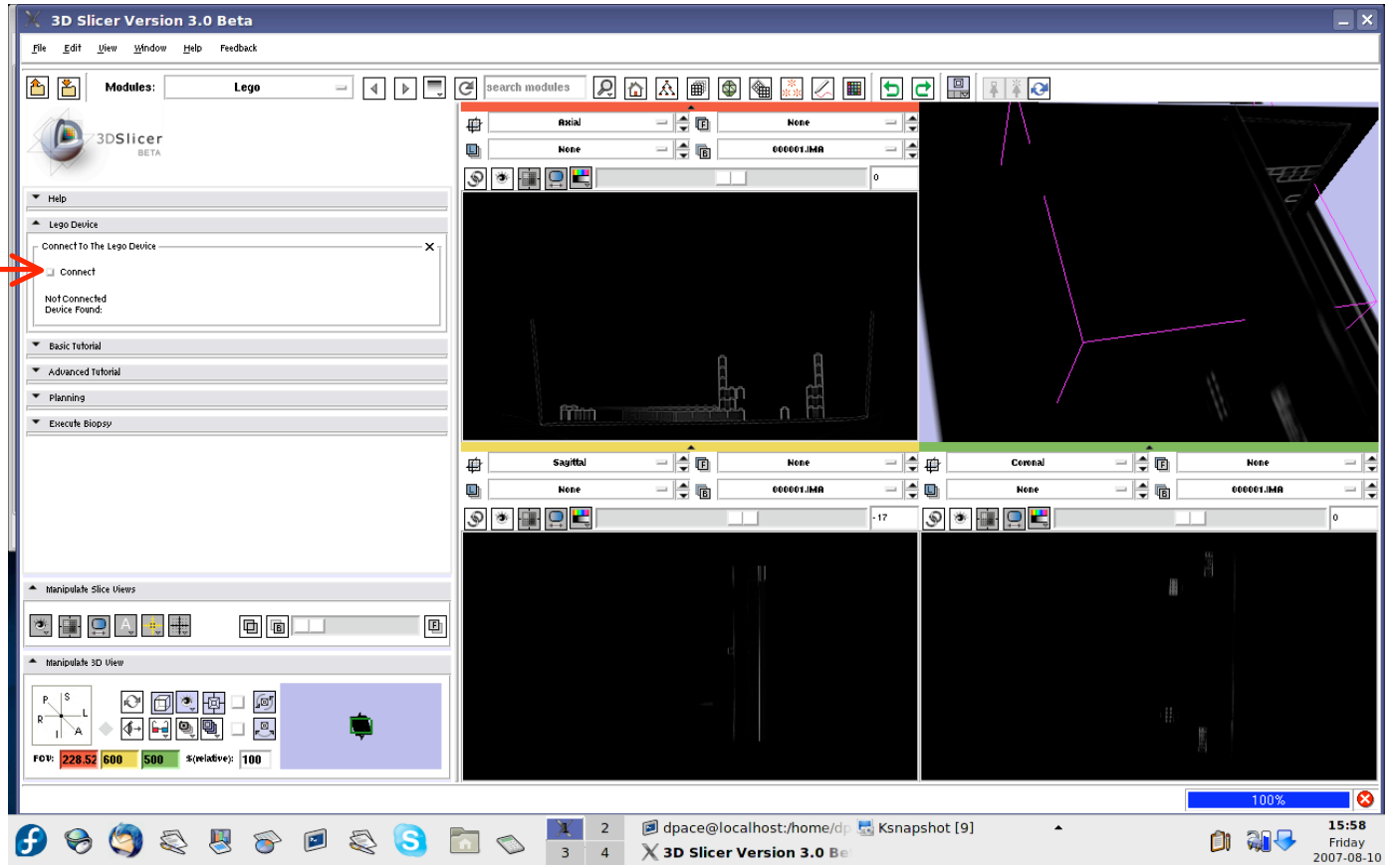
3) Connect to the LEGO robot, continued

Open the "Lego Device" pane



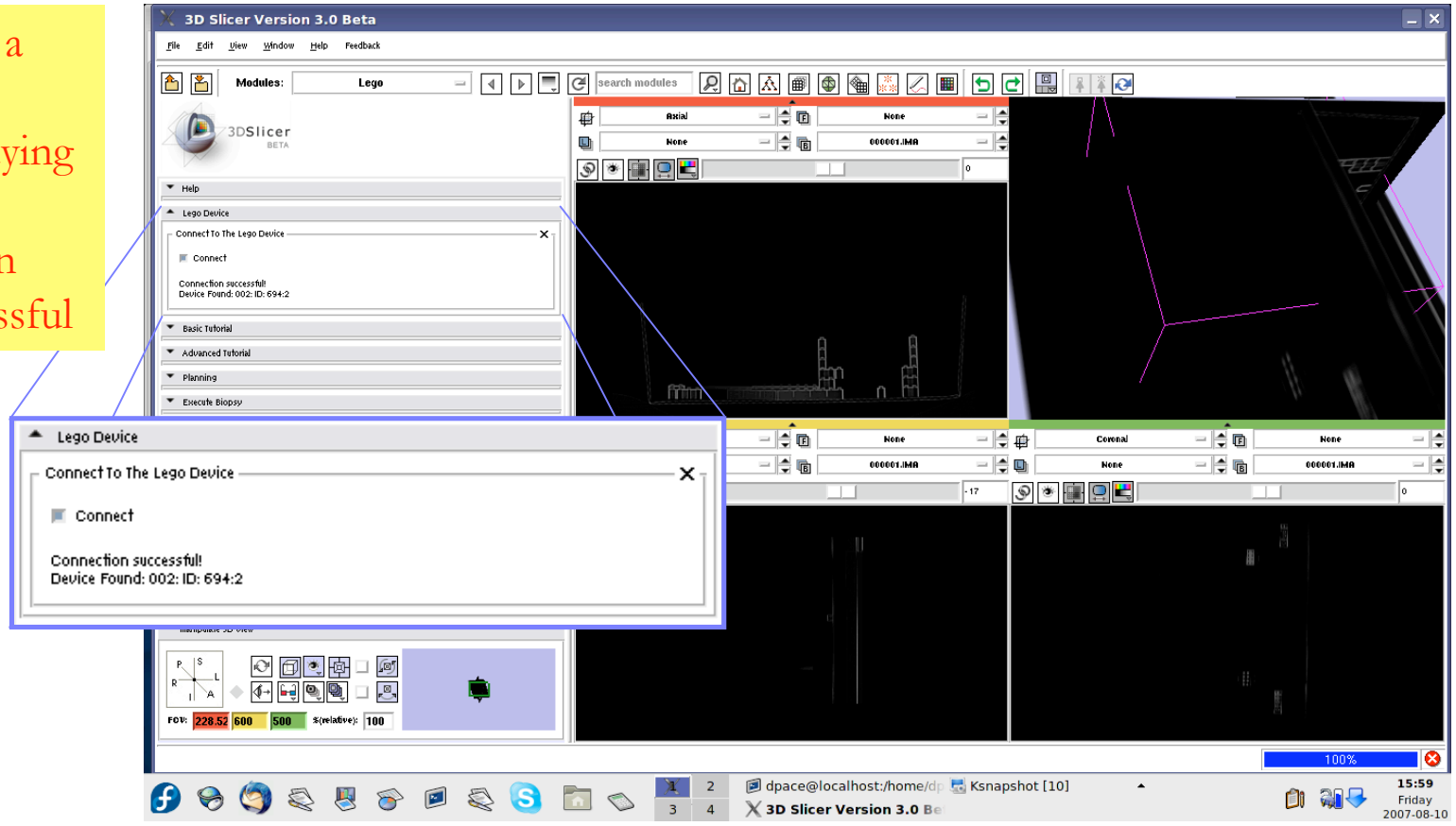
3) Connect to the LEGO robot, continued

Click on the "Connect" check box



3) Connect to the LEGO robot, continued

Wait until a message appears saying that the connection was successful

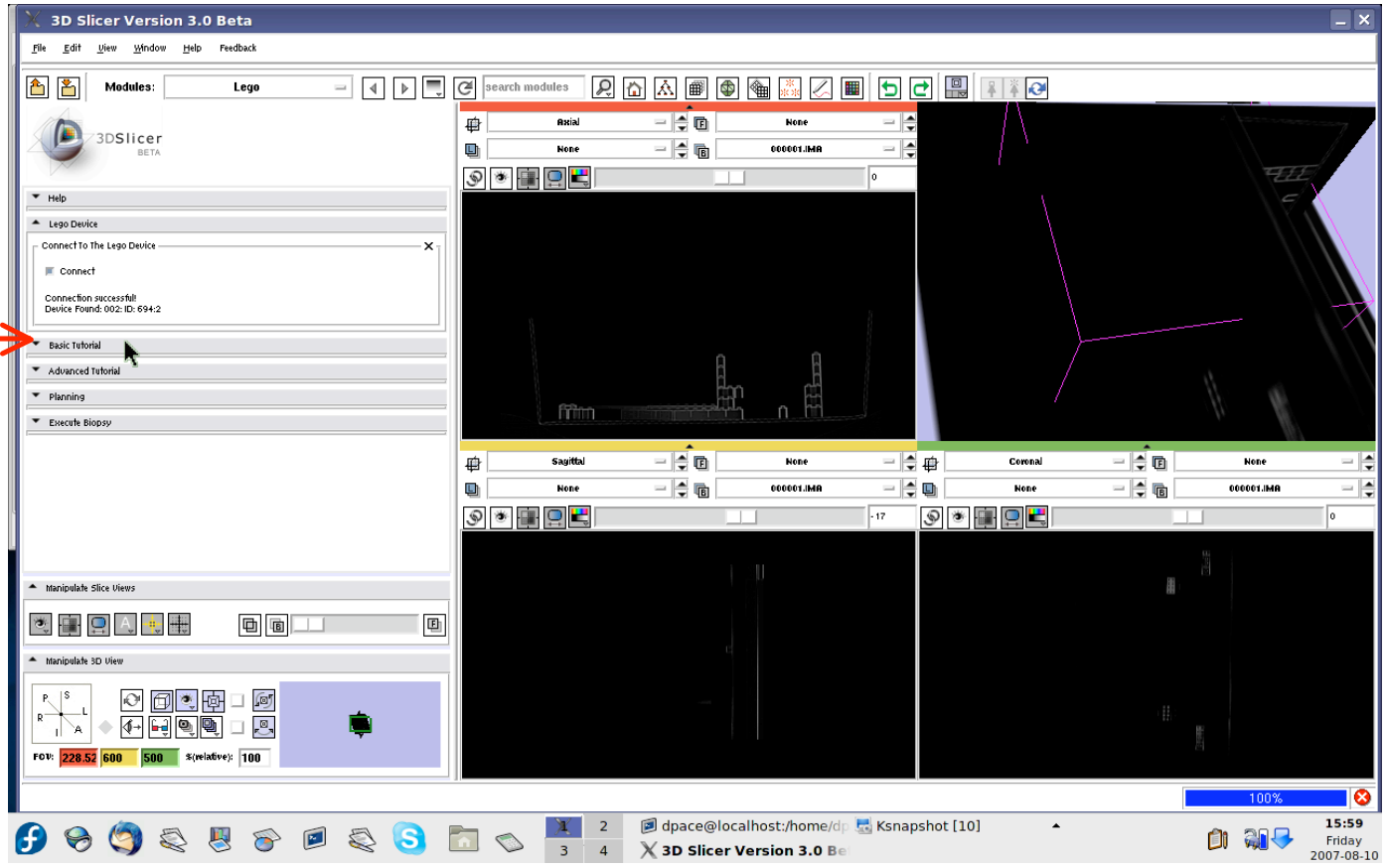


3) Connect to the LEGO robot, continued

- If the connection is not successful, make sure that:
  - You are running as root
  - The LEGO robot is connected to your computer using the USB cable
  - The LEGO robot is turned on

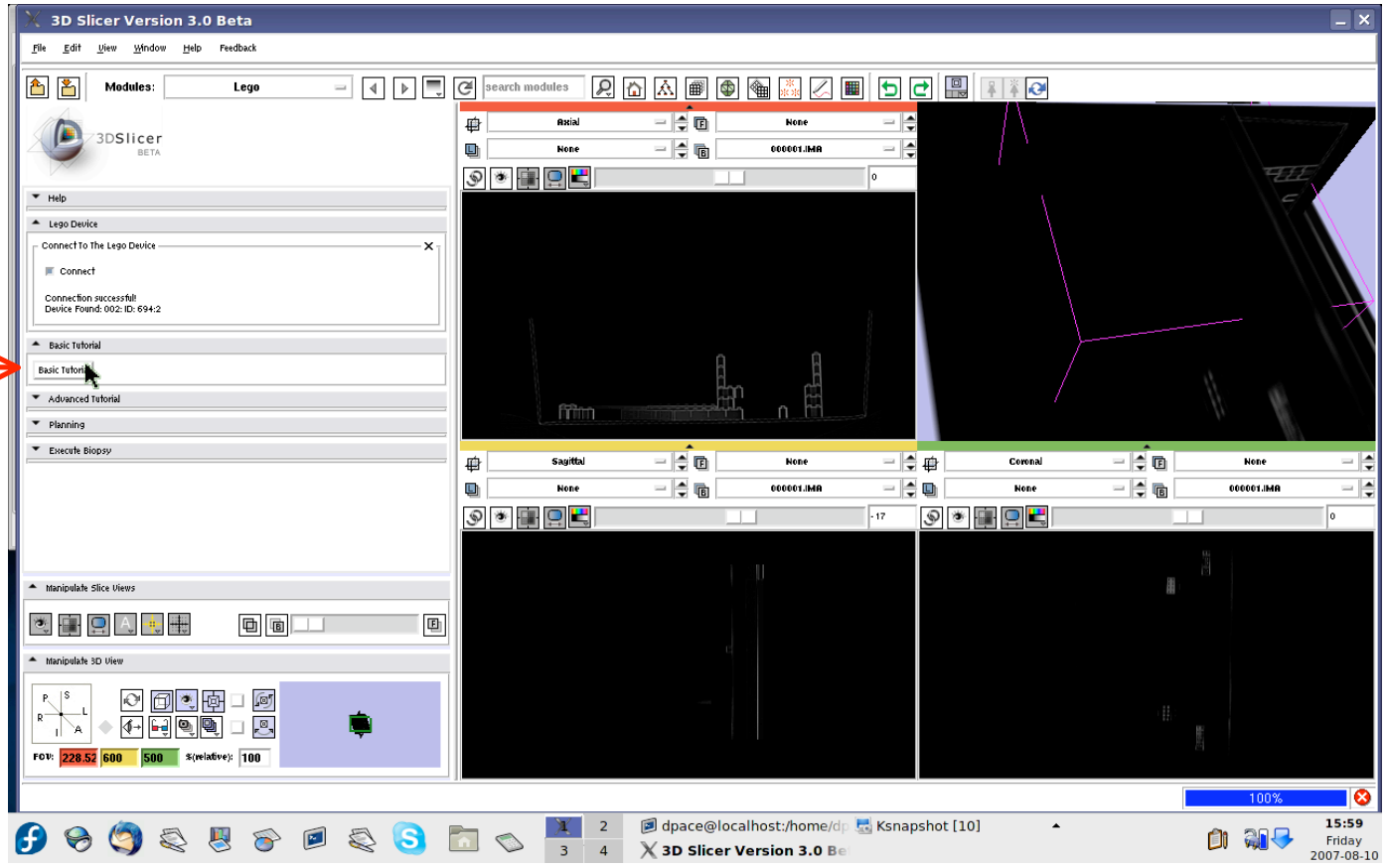
4) Select the basic tutorial option

Open the "Basic Tutorial" pane



4) Select the basic tutorial option, continued

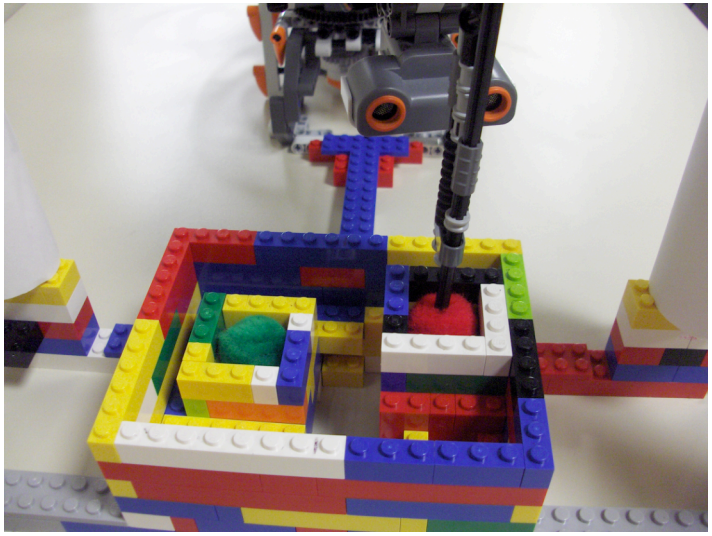
Click on "Basic Tutorial"



5) Planning - select the target coordinate

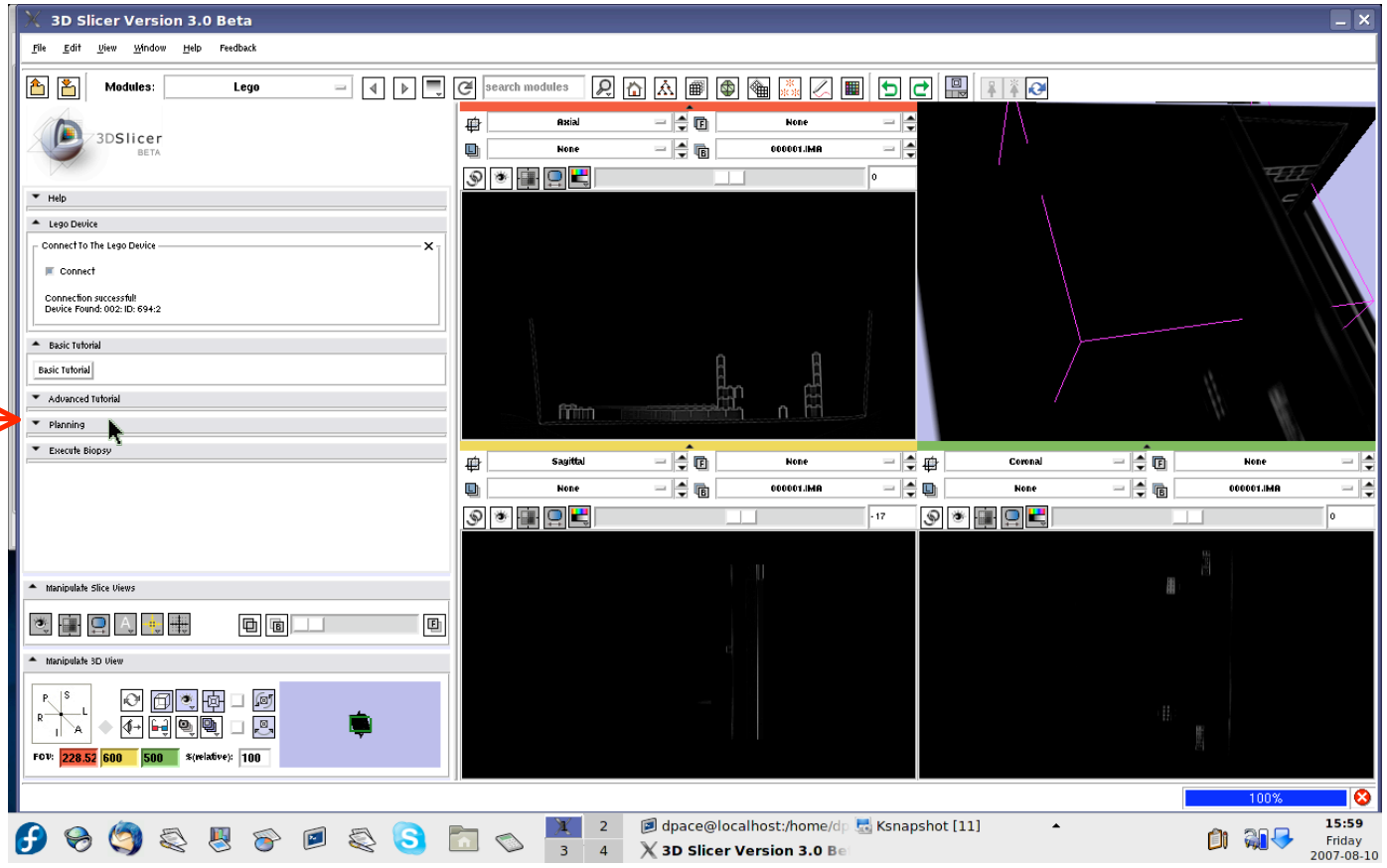
- The target coordinate is the location where you would like the tip of the robot's needle to be at the end of the "biopsy".

- Let's try to have the robot biopsy the red pom-pom.
- We need to find the center of the red pom-pom on the CT volume.



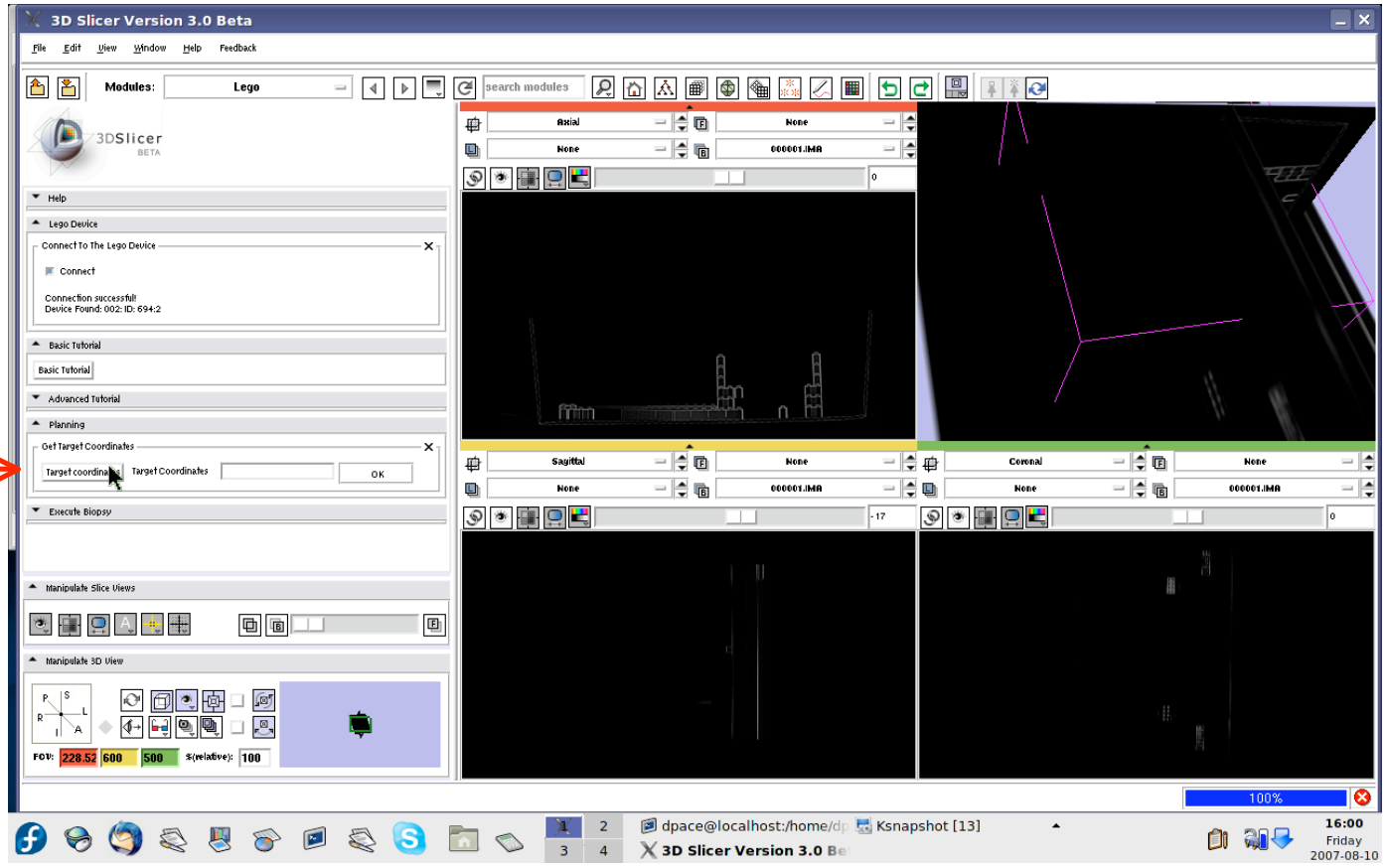
5) Planning - select the target coordinate, continued

Open the "Planning" pane



5) Planning - select the target coordinate, continued

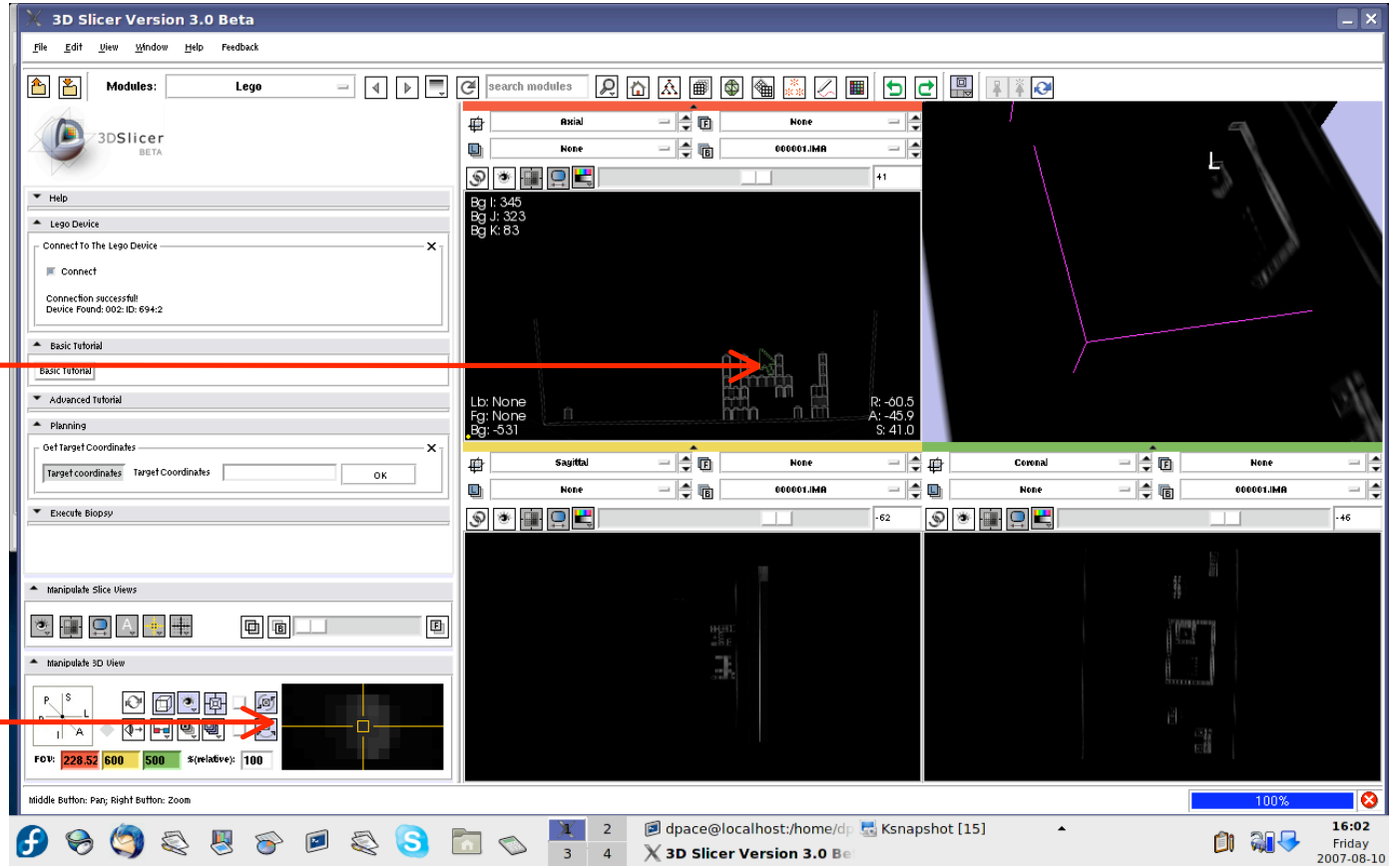
Click on "Target coordinates"



5) Planning - select the target coordinate, continued

Scroll through the 2D viewers using the sliders until you find the center of the red pom-pom. Click on the target coordinate: the **center** of the red pom-pom.

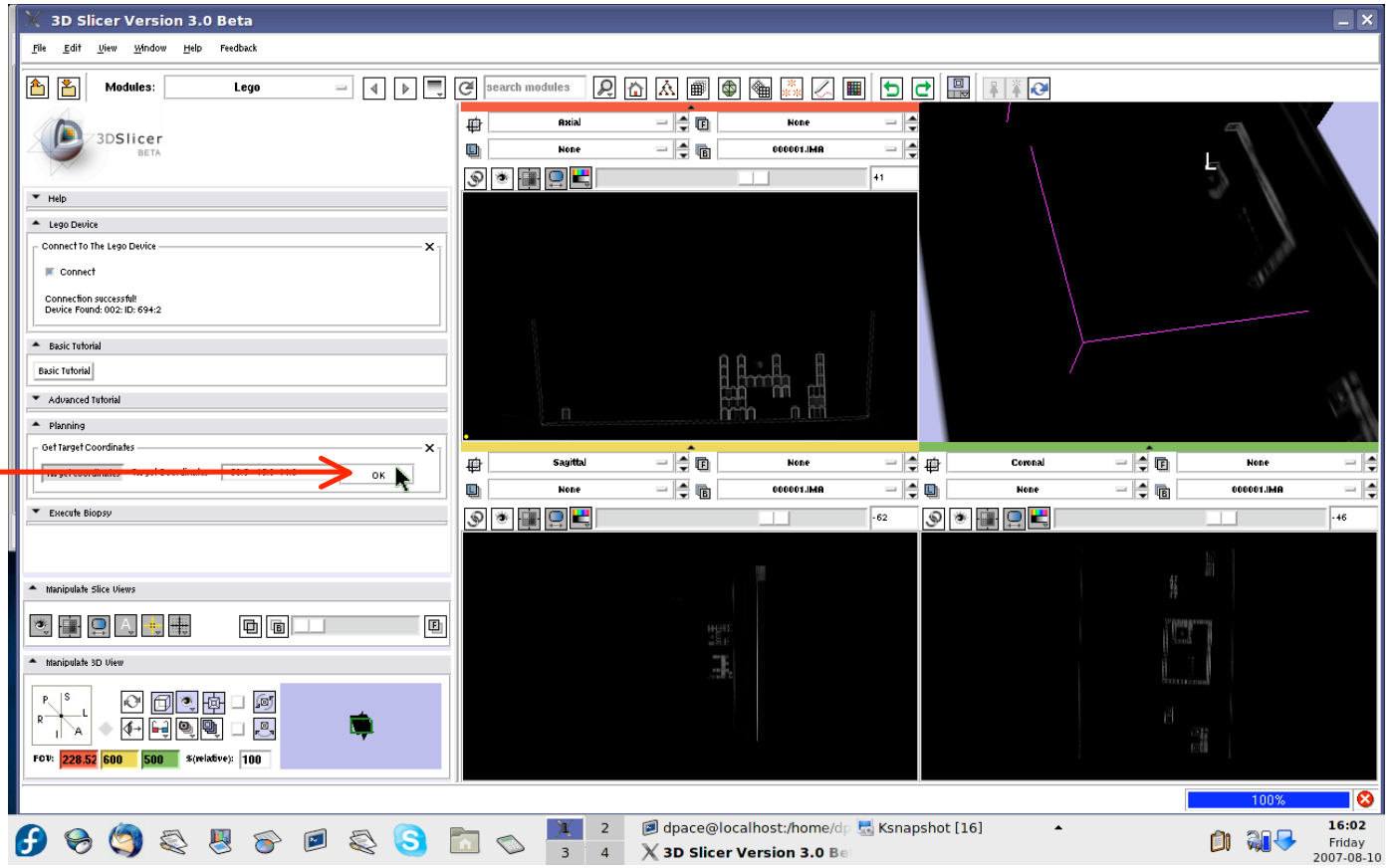
The area around the current cursor position is shown in more detail here.



The protrusions on the phantom's pillars will help you orient yourself when scrolling through the CT volume.

5) Planning - select the target coordinate, continued

Click on "OK" to select the target coordinate

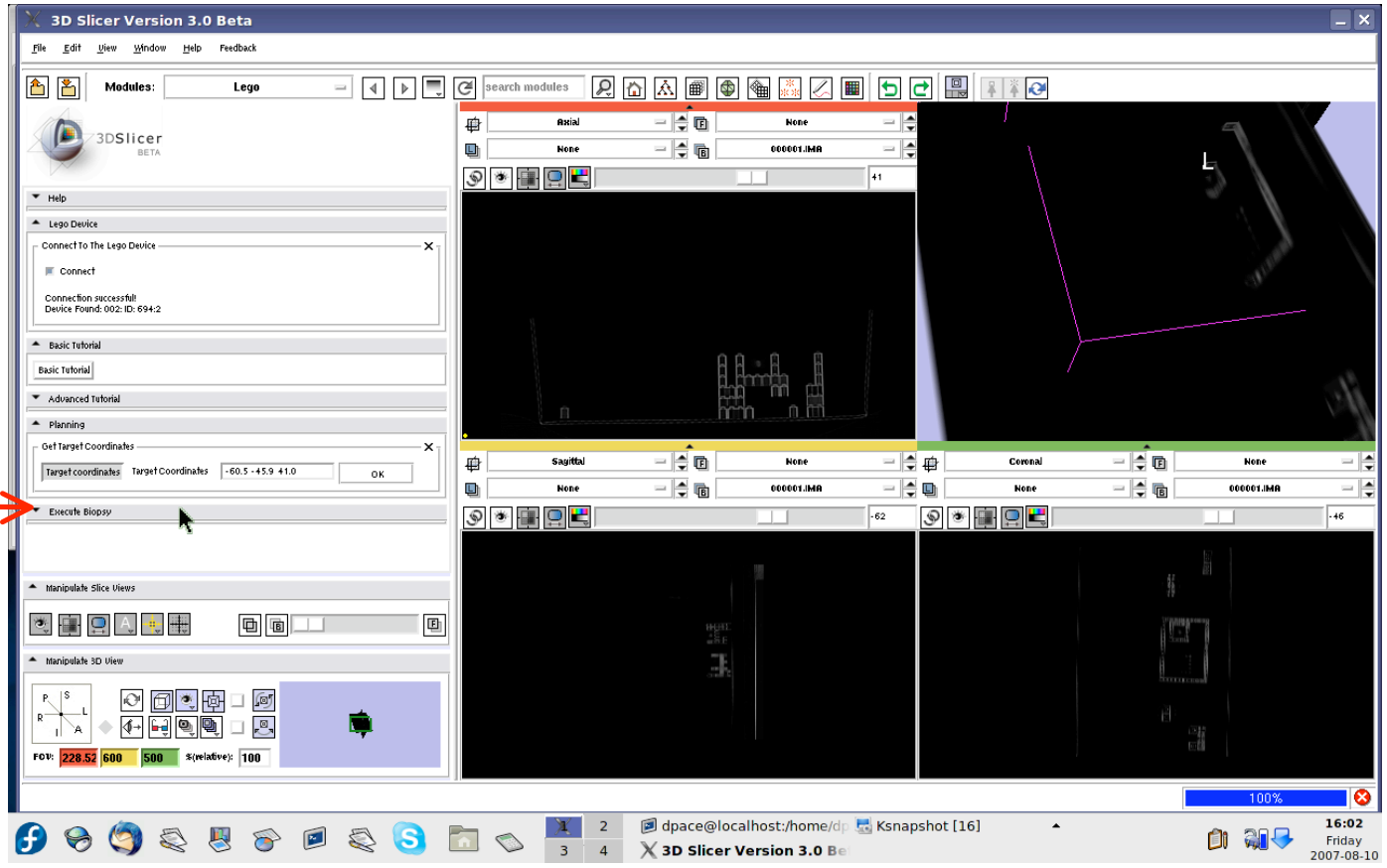


To change the target, click on another point in the CT volume and click on "OK" again.

6) Execute the biopsy

Now the LEGO robot will try to hit the target

Open the "Execute Biopsy" pane



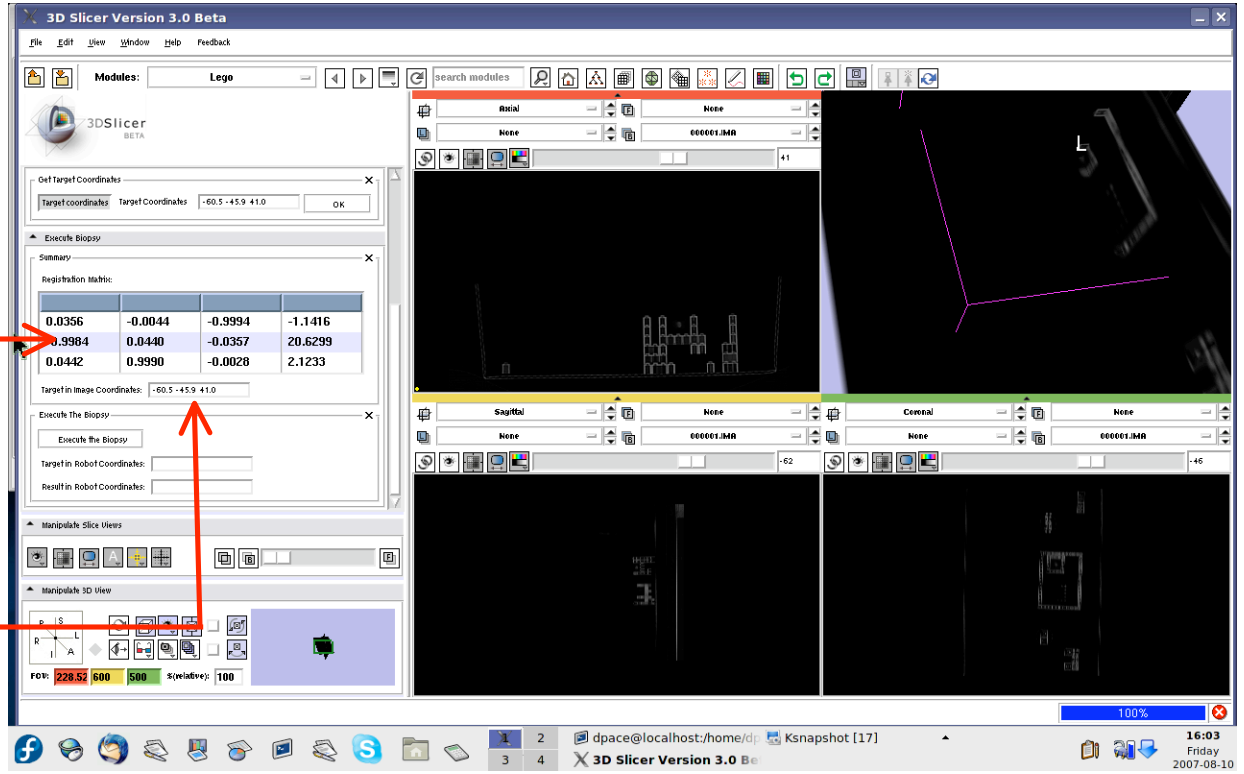
6) Execute the biopsy, continued

Recall:

$$PCS_{3x1} = R_{3x3} \bullet ICS_{3x1} + t_{3x1}$$

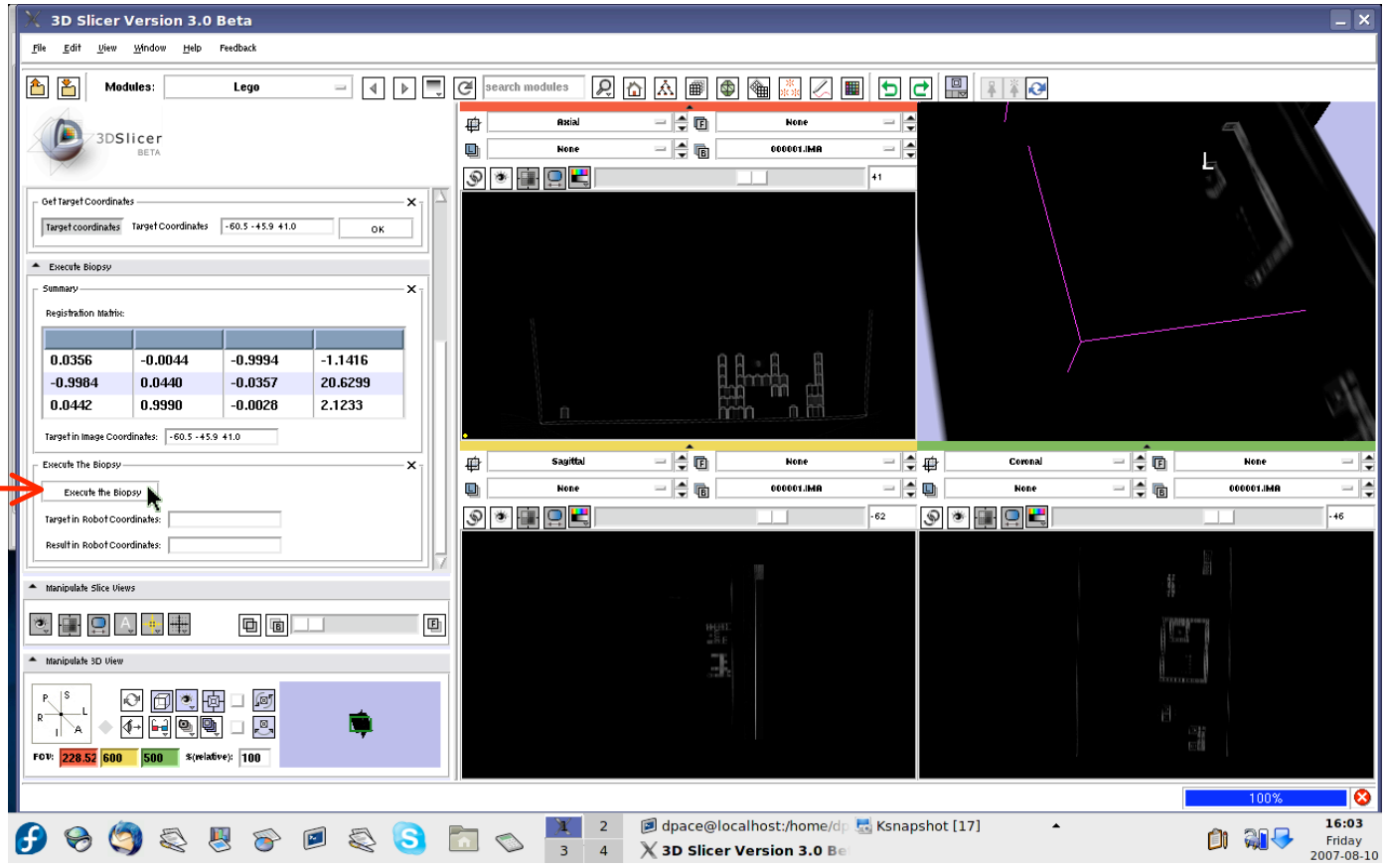
The transformation from the image coordinate system to the patient (robot) coordinate system: columns 1-3 show the rotation matrix *R*; column 4 shows the translation *t*.

The target in the image coordinate system that you selected



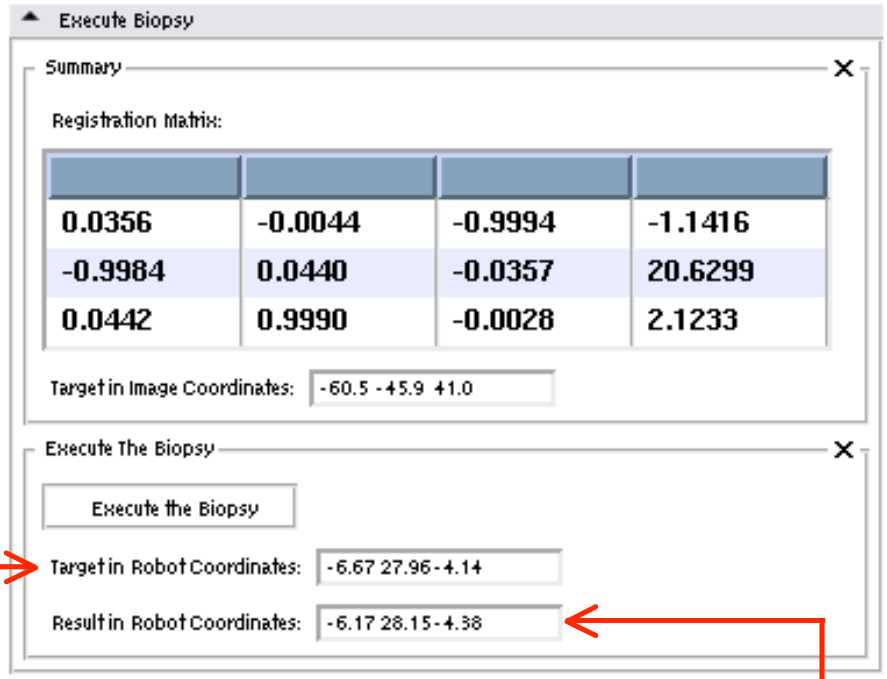
6) Execute the biopsy, continued

Click on "Execute the Biopsy"



The LEGO robot will move to hit the target!

6) Execute the biopsy, continued



The target in the patient (robot) coordinate system

Tracking is done through targeting during the robot's movement

The display of the final needle position in the *PCS* provides **Navigation**

The final needle position in the patient (robot) coordinate system. This coordinate is calculated using rotational information from the robot's motors and knowledge of the robot's structure, and is not completely accurate.

To select additional targets:

- If you would like to try additional targets, simply go back to the "Planning" pane, select another point on the CT volume and click "OK". Then go back to the "Execute Biopsy" pane and click "Execute the Biopsy".

If the LEGO robot does not return to the initial position (centered and all the way back), reset it before selecting another target.

After completing this tutorial section

- You have learned about the following steps in IGT and medical robotics in a hands-on manner:
  - ✓Imaging
  - ✓Preoperative planning
  - ✓Targeting and tracking
  - ✓Navigation

Thanks to

- Terry Peters, Ph.D,(Robarts Research Institute, University of Western Ontario)
- Steven Canvin (The LEGO Group)
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- G. Wade Johnson (Device::USB Developer)
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- Haiying Liu (Surgical Planning Laboratory)
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