



Exploring Peritumoral White Matter Fibers for Neurosurgical Planning

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Surgical Planning Laboratory

Harvard University

Clinical Goal

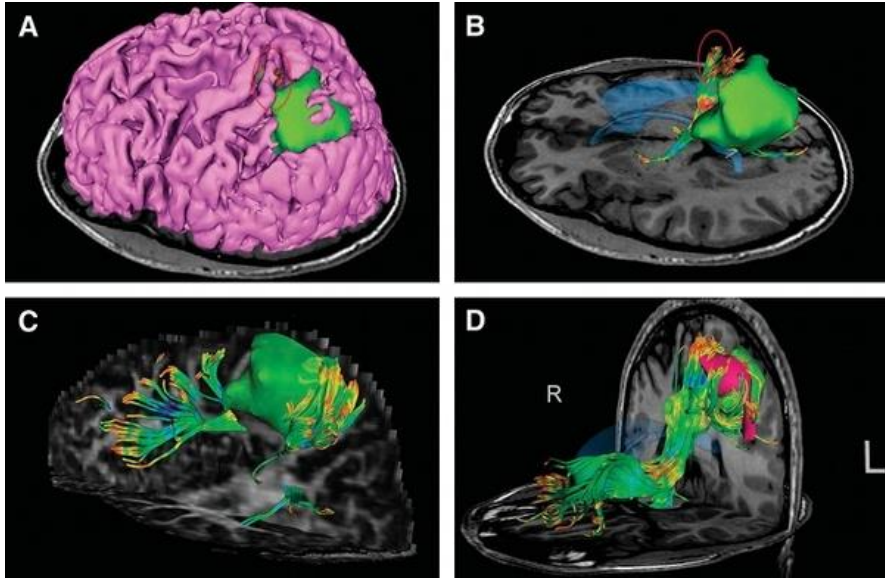
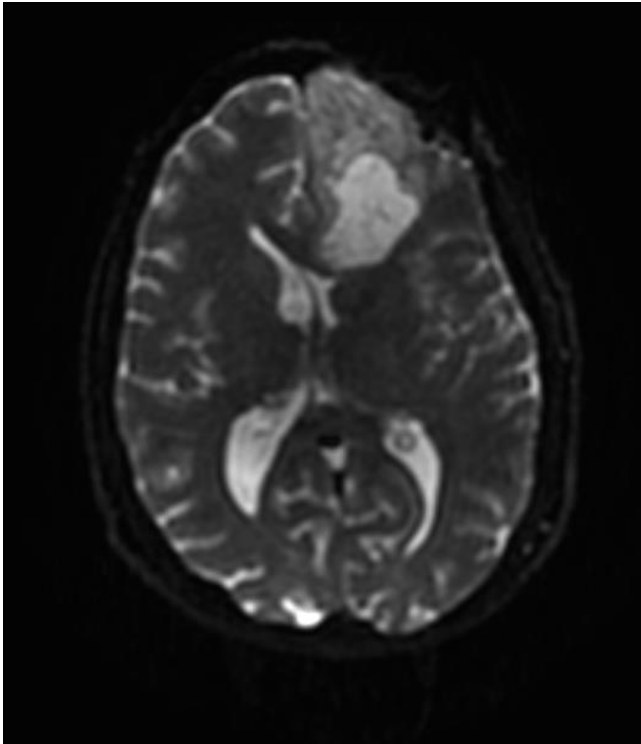


Image Courtesy of Dr. Alexandra Golby, Brigham and Women's Hospital, Boston, MA..

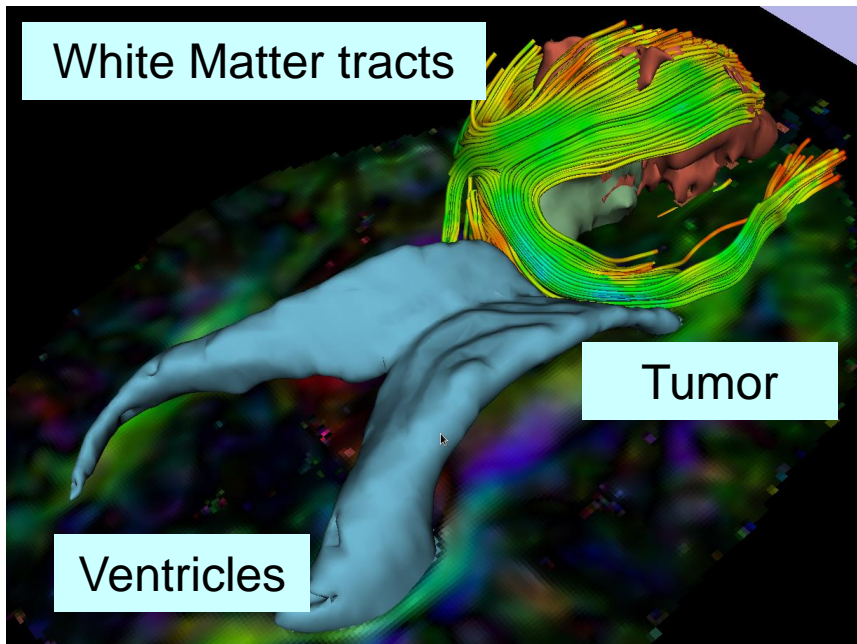
Diffusion Tensor Imaging (DTI) Tractography has the potential to bring valuable spatial information on tumor infiltration and tract displacement for neurosurgical planning of tumor resection.

Clinical Case



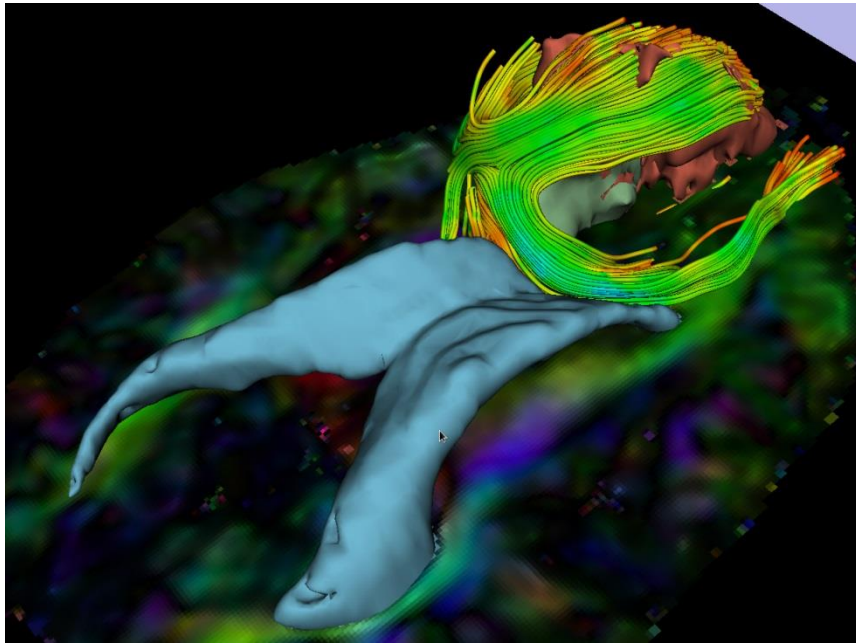
- 35 year-old male diagnosed with Glioblastoma multiforme (GBM)
- Diffusion Weighted Imaging (DWI) acquisition for neurosurgical planning

Clinical Goal



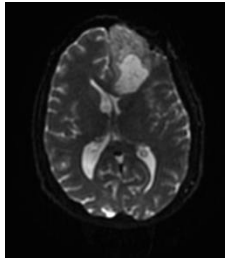
The goal of this tutorial is to explore white matter fibers surrounding a tumor using Diffusion Tensor Imaging (DTI) Tractography.

Image Analysis Pipeline

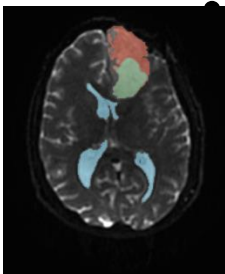


The image analysis pipeline described in this tutorial uses three different algorithms: the “Grow Cut” algorithm for segmentation of the tumor parts, the Marching Cube algorithm for surface modeling, and the single tensor streamline tractography algorithm for tract generation.

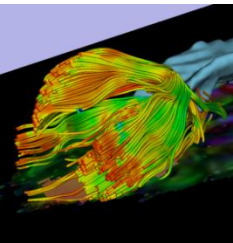
Overview of the analysis pipeline



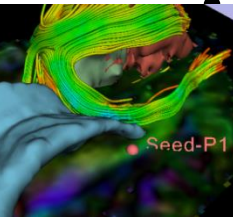
Part 1: Loading & Visualization of Diffusion Data



Part 2: Segmentation of the ventricles, and solid and cystic parts of the tumor

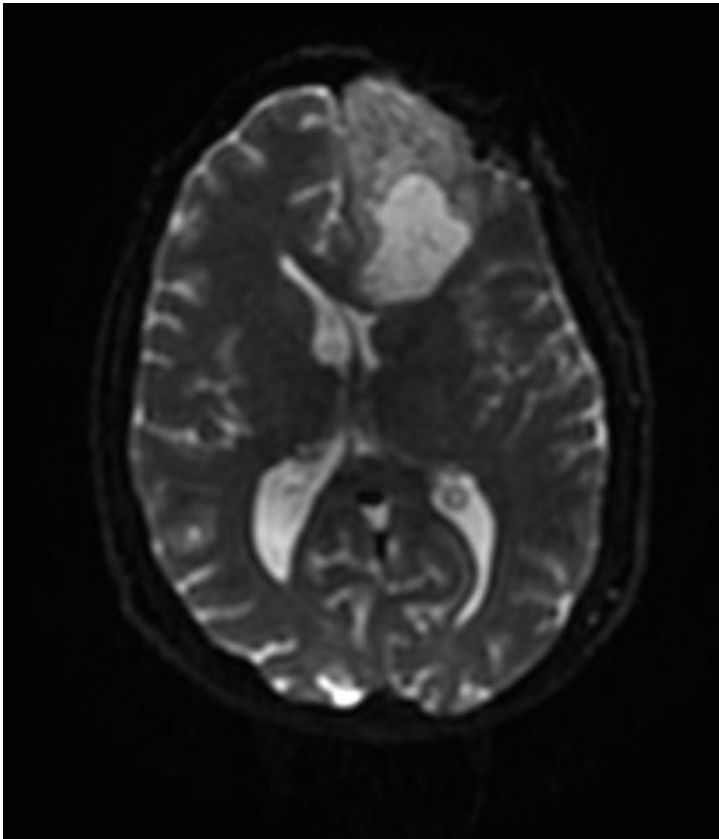


Part 3: Tractography reconstruction of the white matter fibers in the peri-tumoral volume

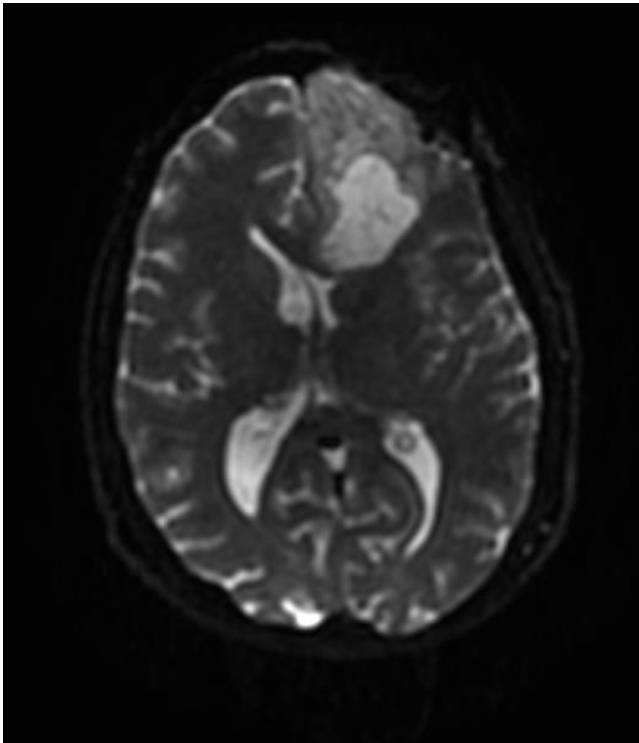


Part 4: Tractography exploration of the ipsilateral and contralateral side

Part 1: Loading and Visualization of Diffusion Data



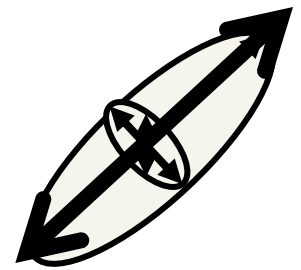
Diffusion Tensor Imaging



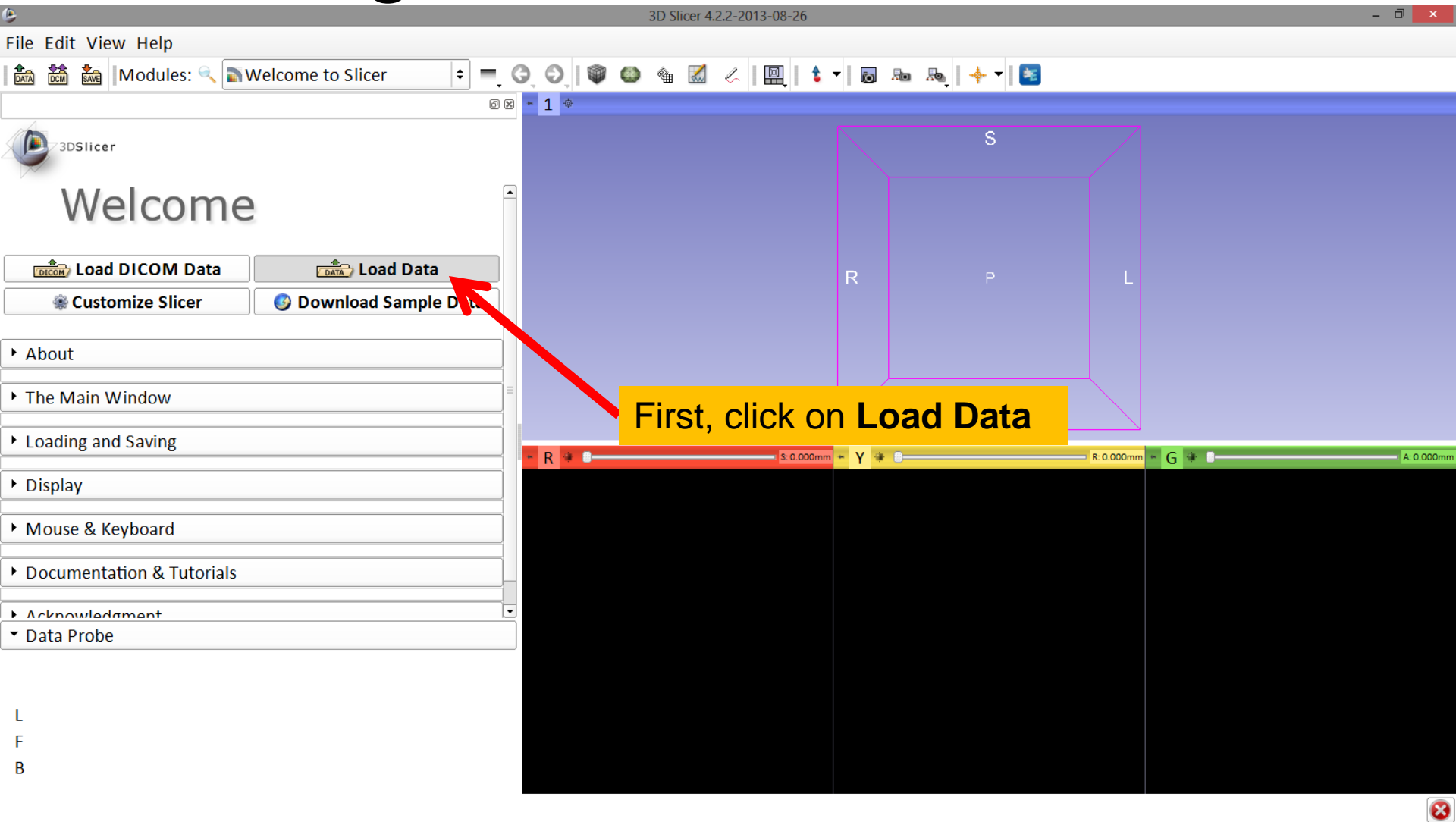
$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

(Stejskal and Tanner 1965, Basser 1994)

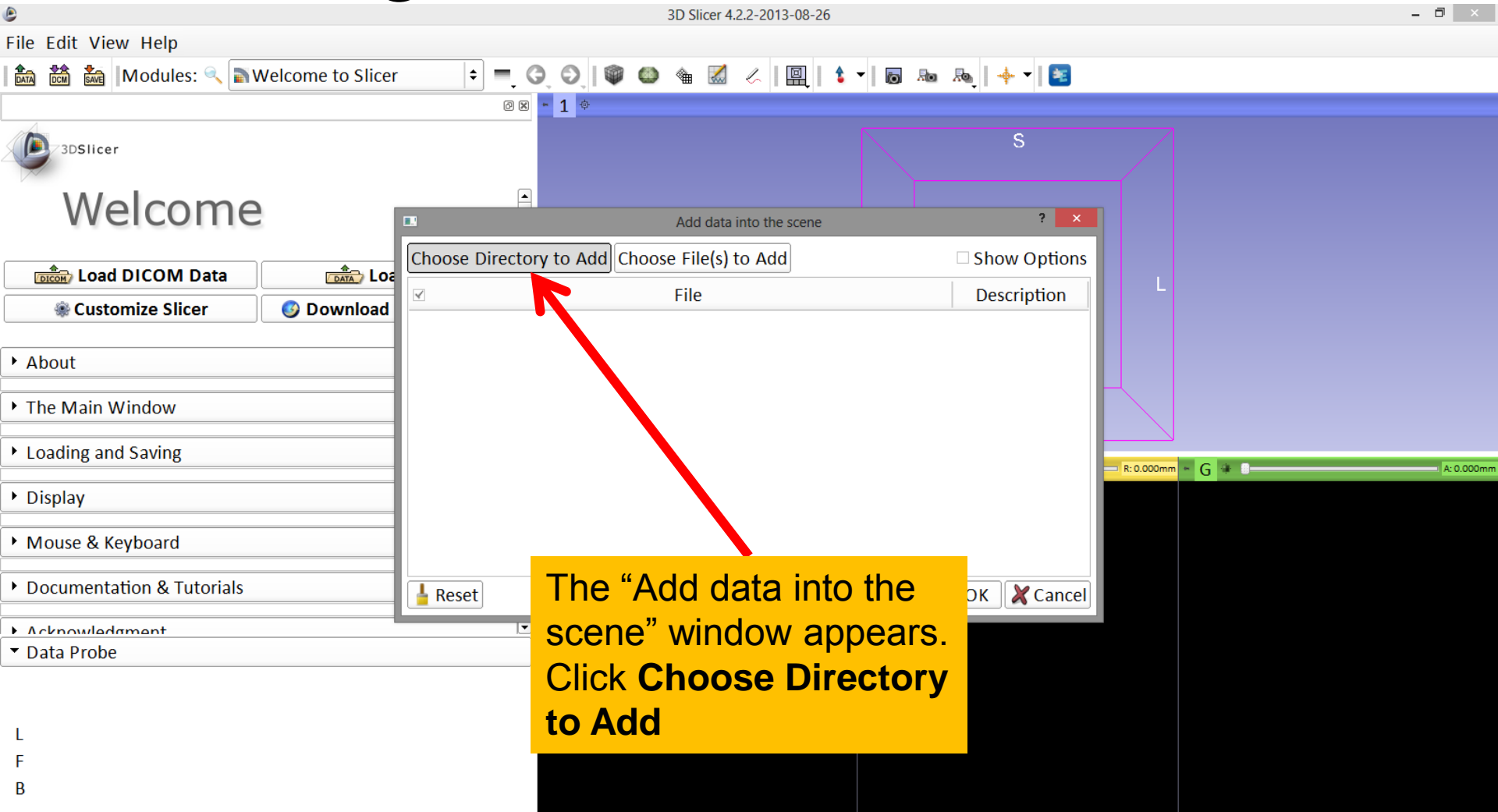
$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



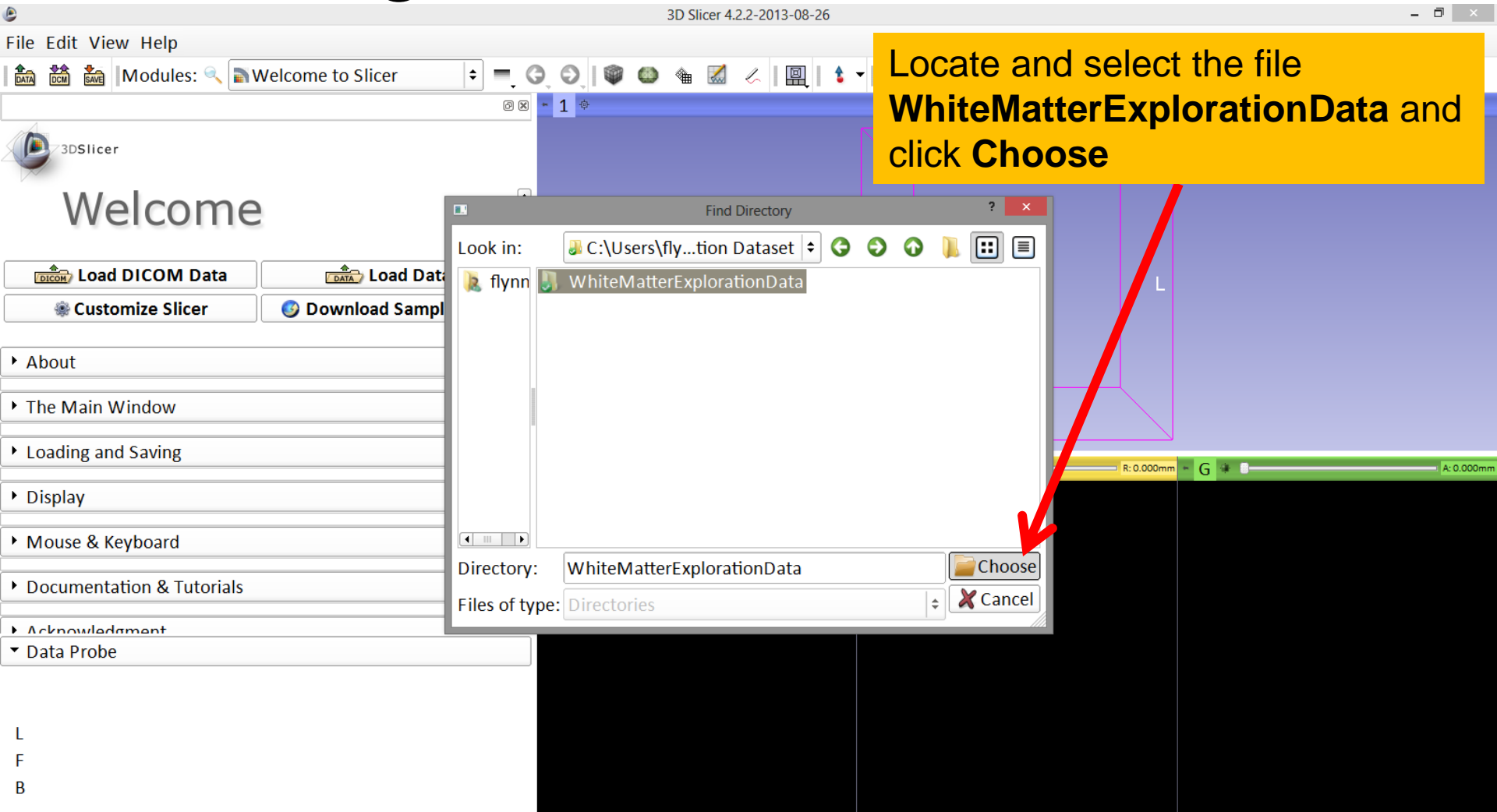
Loading DTI and Baseline Data



Loading DTI and Baseline Data



Loading DTI and Baseline Data



Loading DTI and Baseline Data

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Welcome to Slicer

3DSlicer

Welcome

Load DICOM Data | Load Data | Customize Slicer | Download

About | The Main Window | Loading and Saving | Display | Mouse & Keyboard | Documentation & Tutorials | Acknowledgment | Data Probe

Add data into the scene

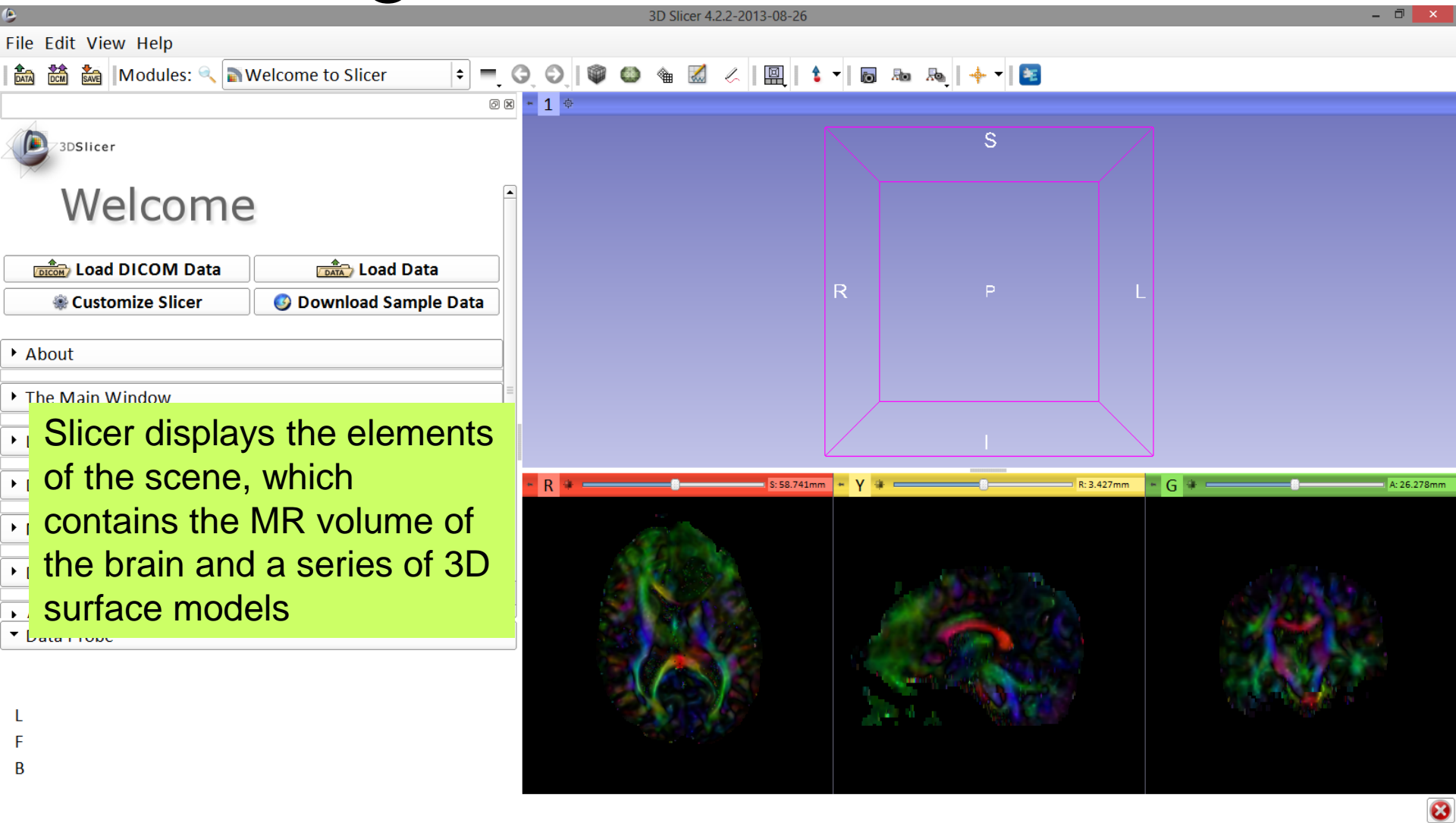
Choose Directory to Add | Choose File(s) to Add | Show Options

File	Description
<input checked="" type="checkbox"/> .../datasets/WhiteMatterExplorationData/BaselineVolume.nrrd	Volume
<input checked="" type="checkbox"/> ...cer4/datasets/WhiteMatterExplorationData/DTIVolume.nhdr	Volume
<input type="checkbox"/> ...r4/datasets/WhiteMatterExplorationData/DTIVolume.raw.gz	Volume

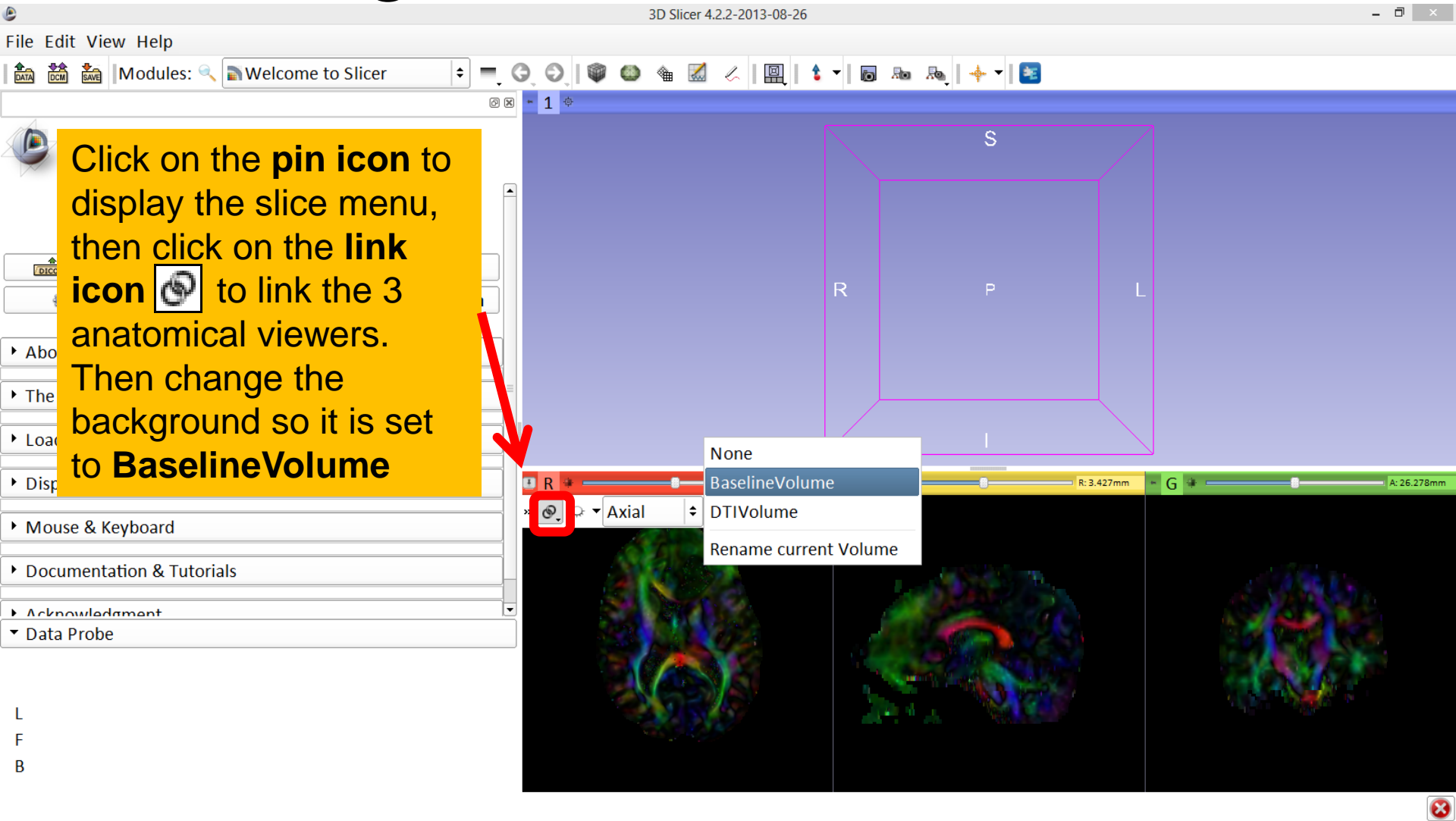
Reset | OK | Cancel

Check off the Volumes **BaselineVolume.nrrd** and **DTIVolume.nhdr** click **OK**

Loading DTI and Baseline Data



Loading DTI and Baseline Data



Loading DTI and Baseline Data

File Edit View Help

DATA DCM SAVE Modules:

3DSlicer

Welcome

Load DICOM Data

Customize Slicer

About

The Main Window

Loading and Saving

Display

Mouse & Keyboard

Documentation & Tutorial

Acknowledgment

Data Probe

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All Modules

Annotations

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DICOM

Editor

Markups

Models

Scene Views

Transforms

View Controllers

Volume Rendering

Volumes

Welcome to Slicer

Wizards

Informatics

Registration

Segmentation

Quantification

Diffusion

IGT

Filtering

Surface Models

Converters

Endoscopy

Utilities

Developer Tools

Legacy

Testing

Work in Progress

3D Slicer 4.2.2-2013-08-26

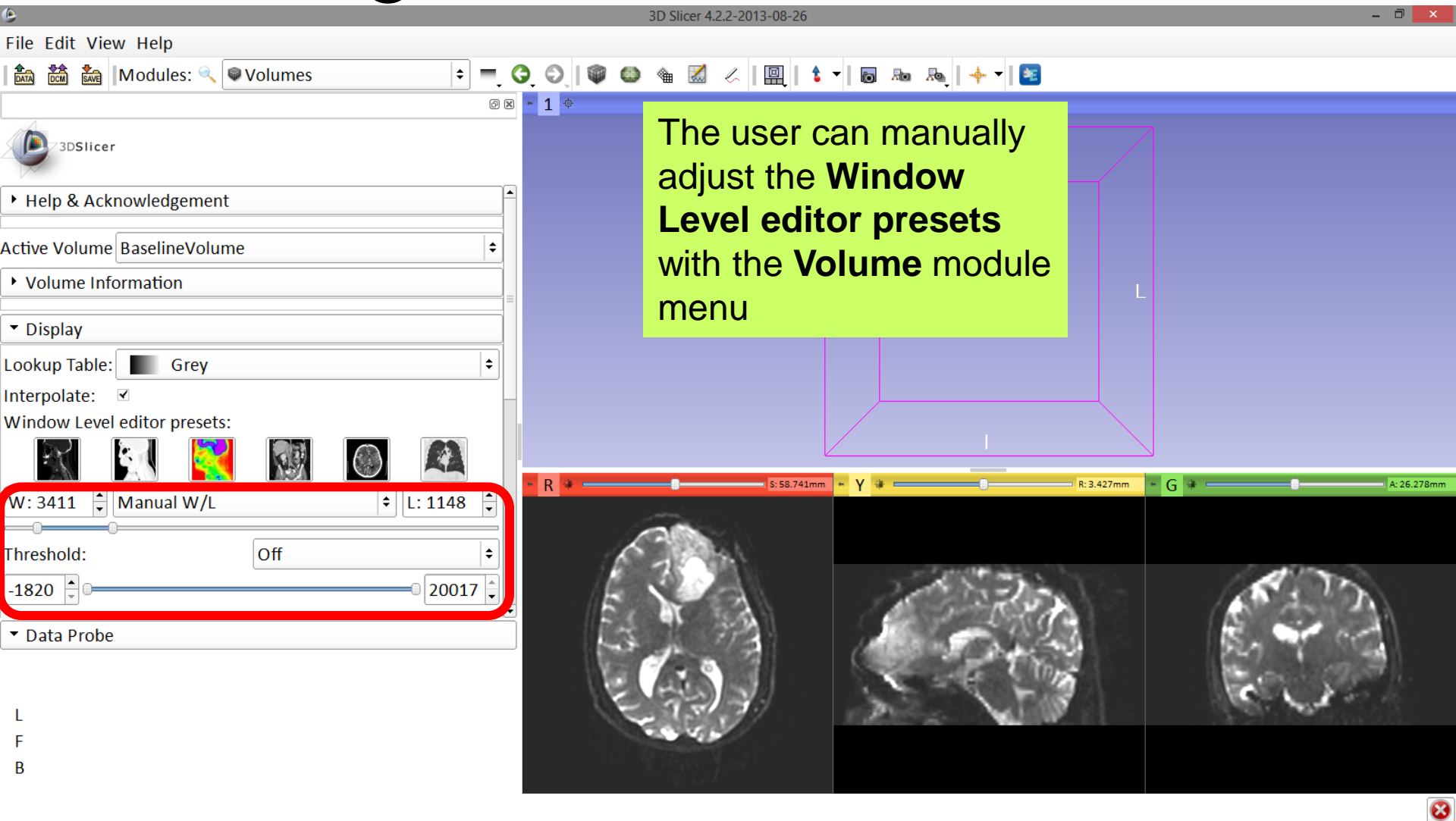
Select the **Volumes** module from the Modules menu

S

I

S: 58.741mm Y R: 3.427mm G A: 26.278mm

Loading DTI and Baseline Data



Loading DTI and Baseline Data

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume: BaselineVolume

Volume Information

Display

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 3411 Manual W/L L: 1148

Threshold: Off

-1820 20017

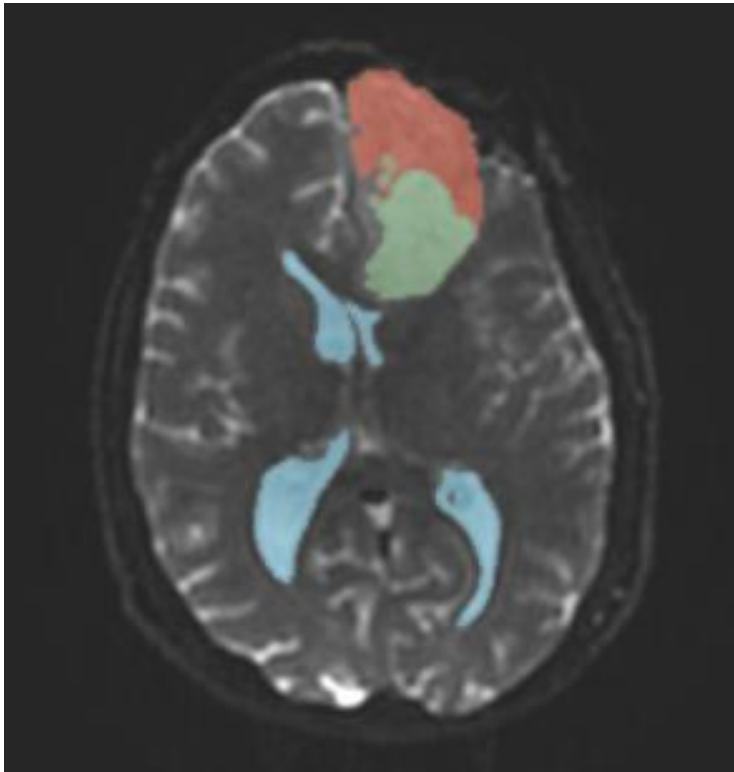
Data Probe

L
F
B

Layout menu options:

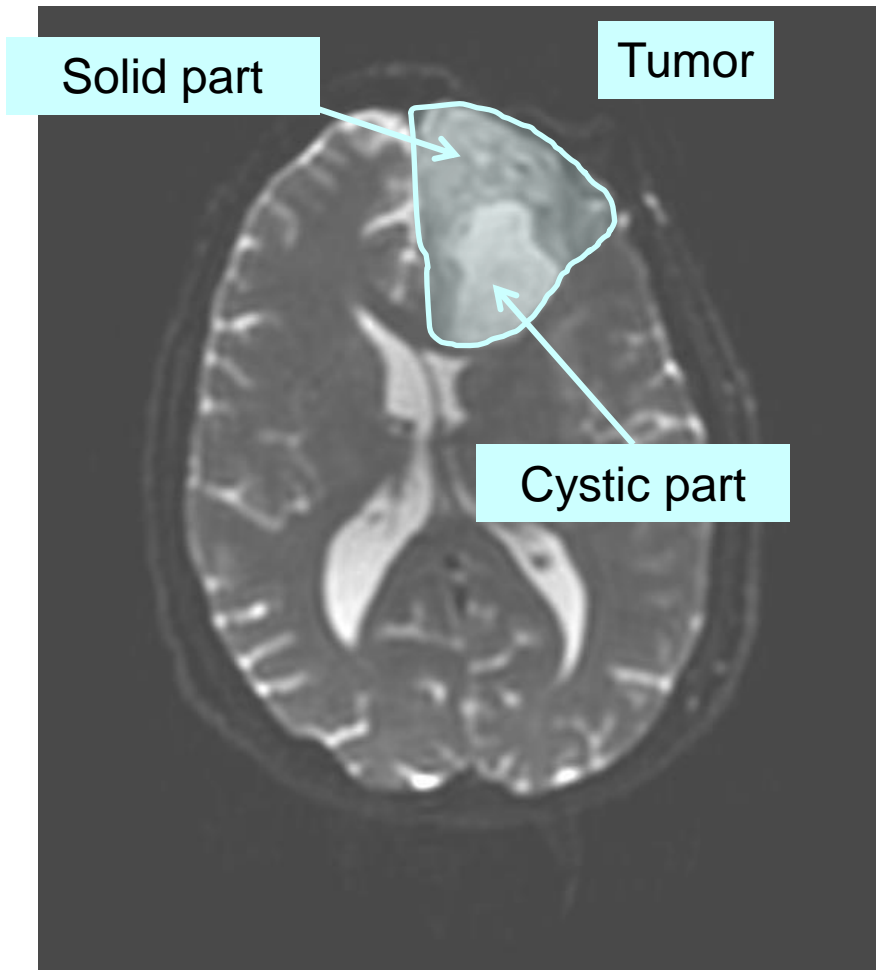
- Conventional
- Conventional Widescreen
- Conventional Quantitative
- Four-Up
- Four-Up Quantitative
- Dual 3D
- Triple 3D
- 3D only
- One-Up Quantitative
- Red slice only**
- Yellow slice only
- Green slice only
- Tabbed 3D
- Tabbed slice
- Compare
- Compare Widescreen
- Compare Grid
- Three over three
- Three Over Three Quantitative
- Four over four
- Two over Two
- Side by side

Click on the Layout menu and select the layout **Red slice only**



Part 1: Segmenting the tumor and ventricles

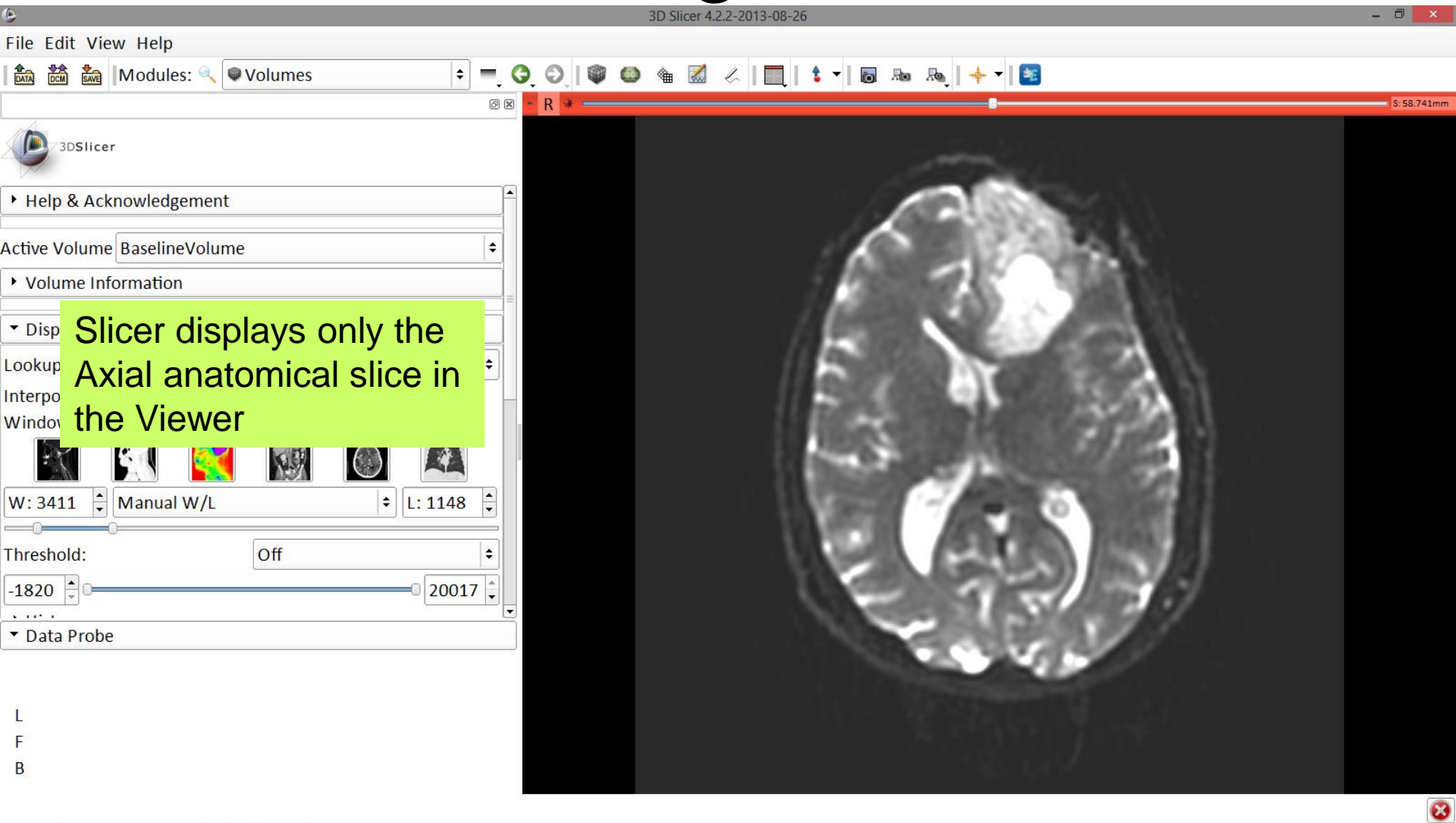
Tumor Segmentation



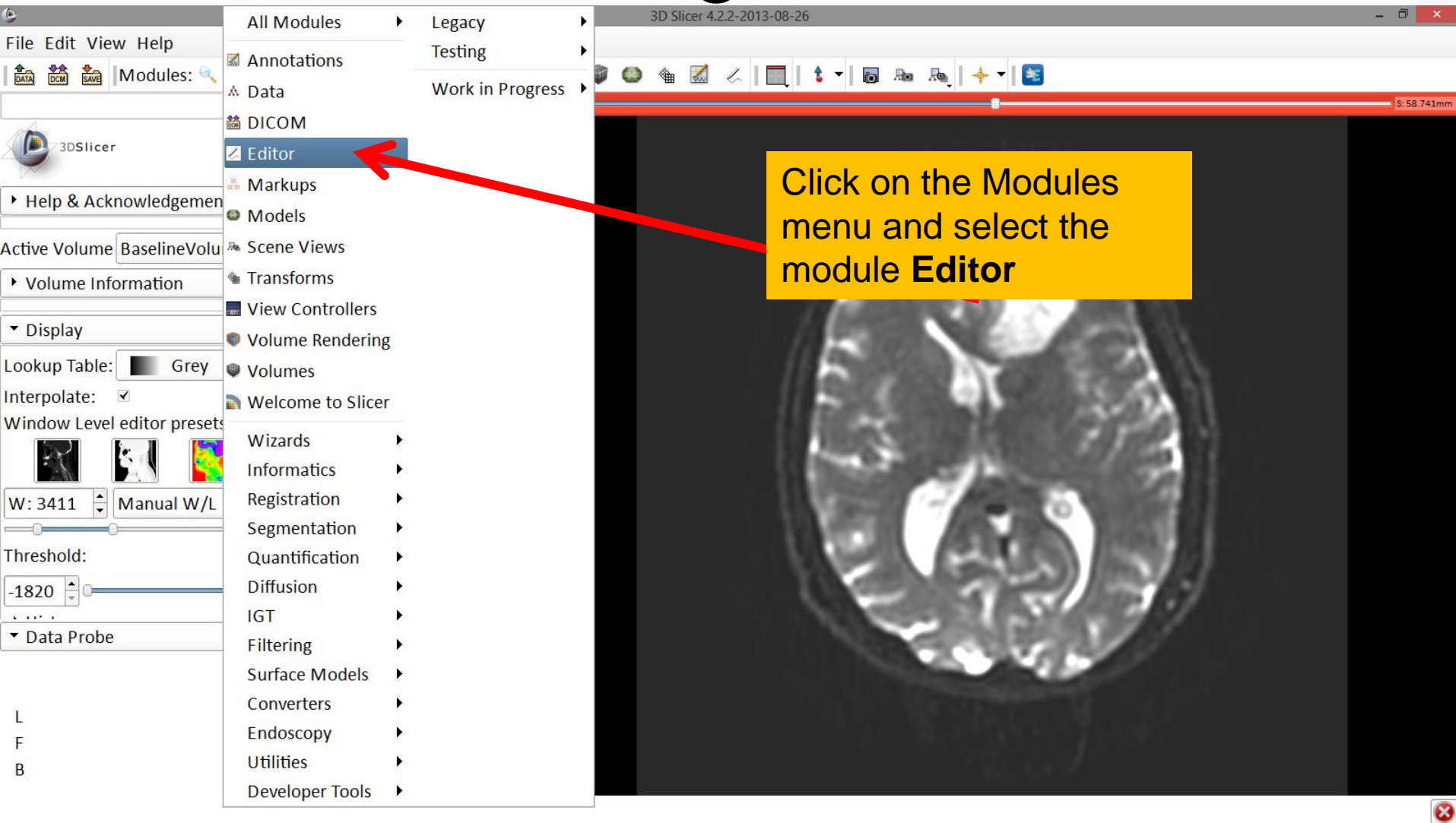
The tumor in this clinical case is composed of two parts: a solid part, and a cystic part.

In this section, we will segment the different parts of the tumor using a Grow Cut Segmentation algorithm.

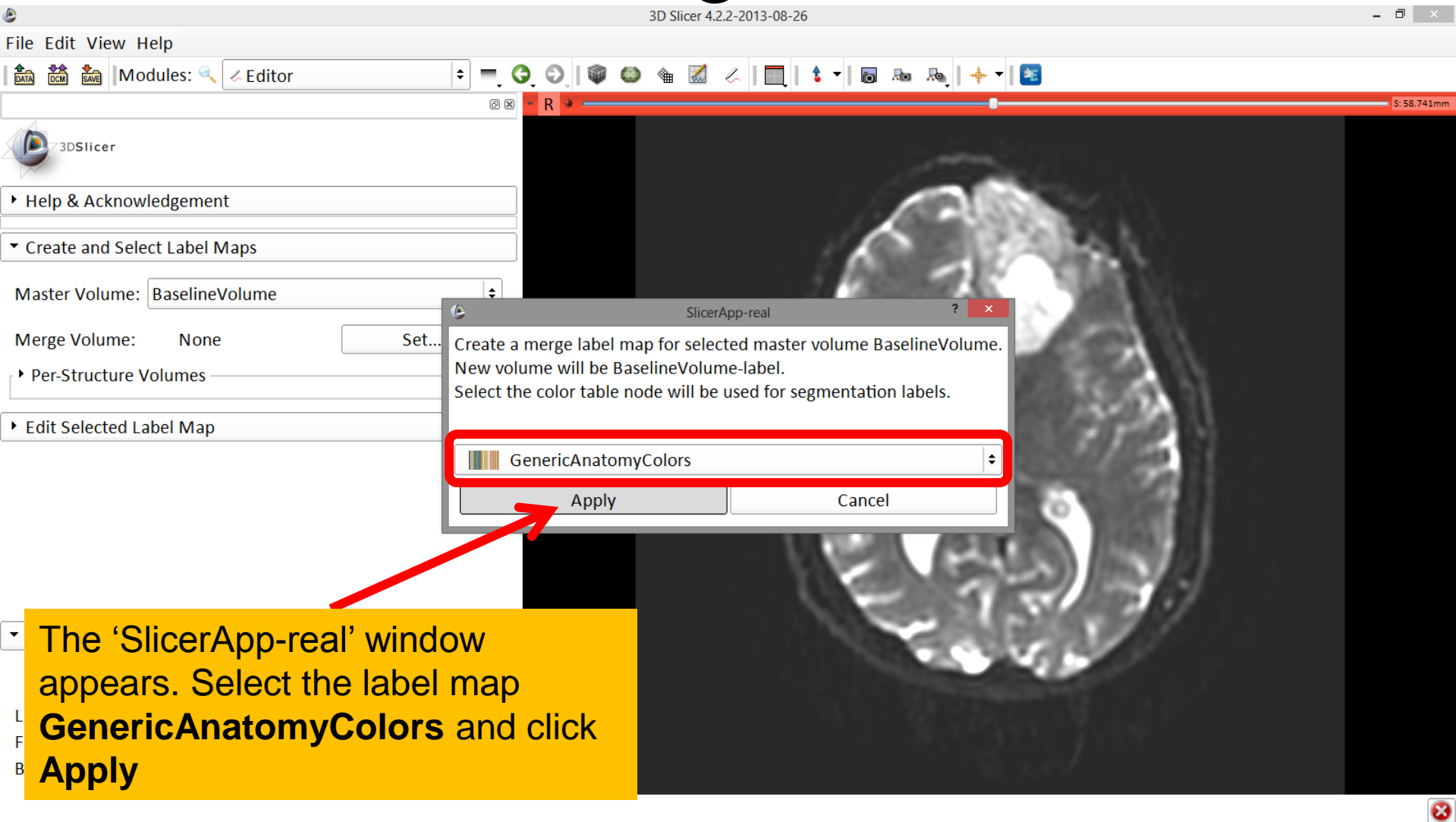
Tumor Segmentation



Tumor Segmentation



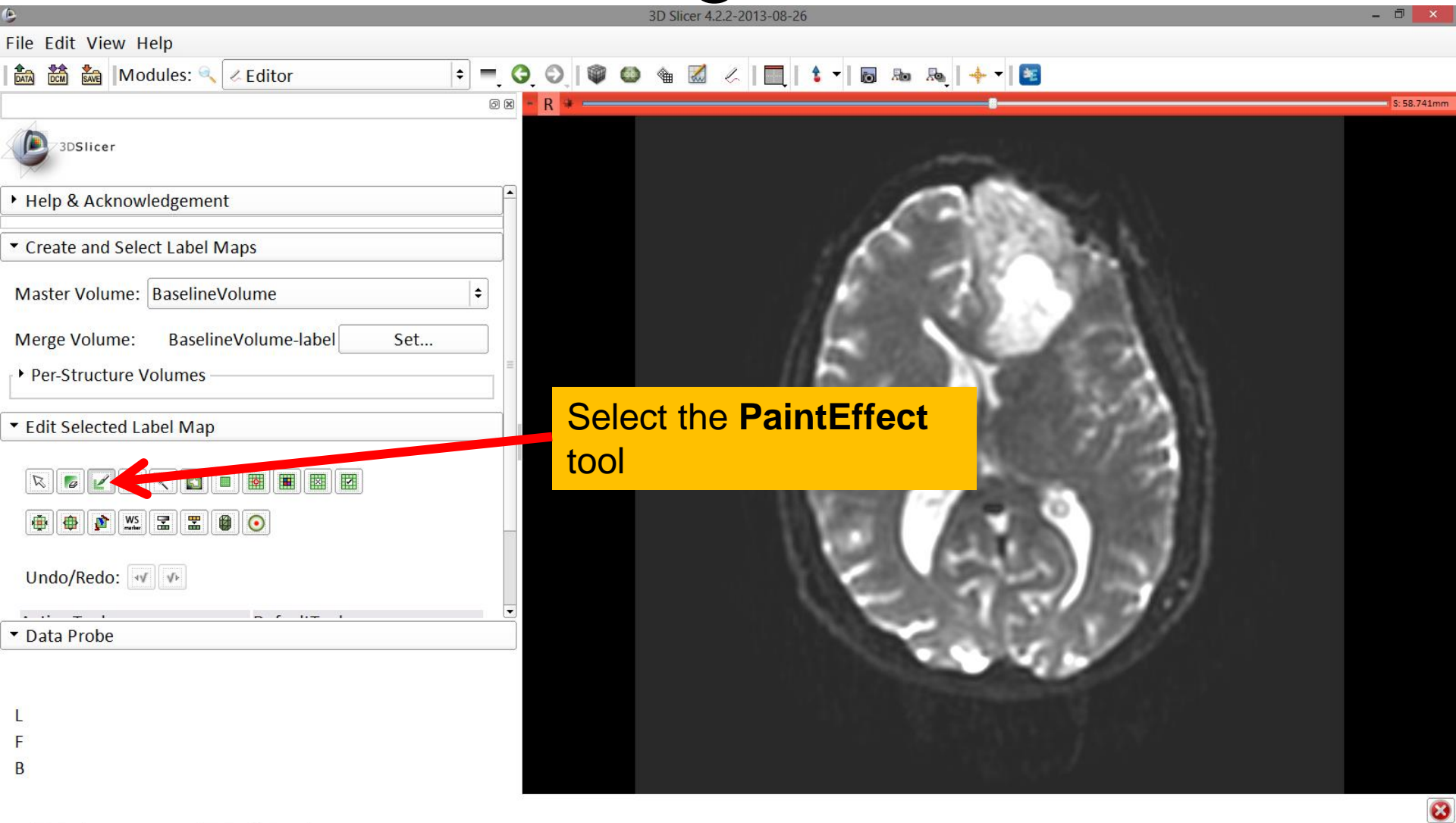
Tumor Segmentation



The screenshot shows the 3D Slicer interface with a brain MRI scan. A dialog box titled 'SlicerApp-real' is open, displaying the following text: 'Create a merge label map for selected master volume BaselineVolume. New volume will be BaselineVolume-label. Select the color table node will be used for segmentation labels.' Below the text is a dropdown menu with 'GenericAnatomyColors' selected, highlighted by a red rectangle. A red arrow points to the 'Apply' button. The background shows the 3D Slicer interface with a brain MRI scan and various toolbars.

The 'SlicerApp-real' window appears. Select the label map **GenericAnatomyColors** and click **Apply**

Tumor Segmentation



Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Per-Structure Volumes

Edit Selected Label Map

Active Tool: PaintEffect

Label: region 1 293

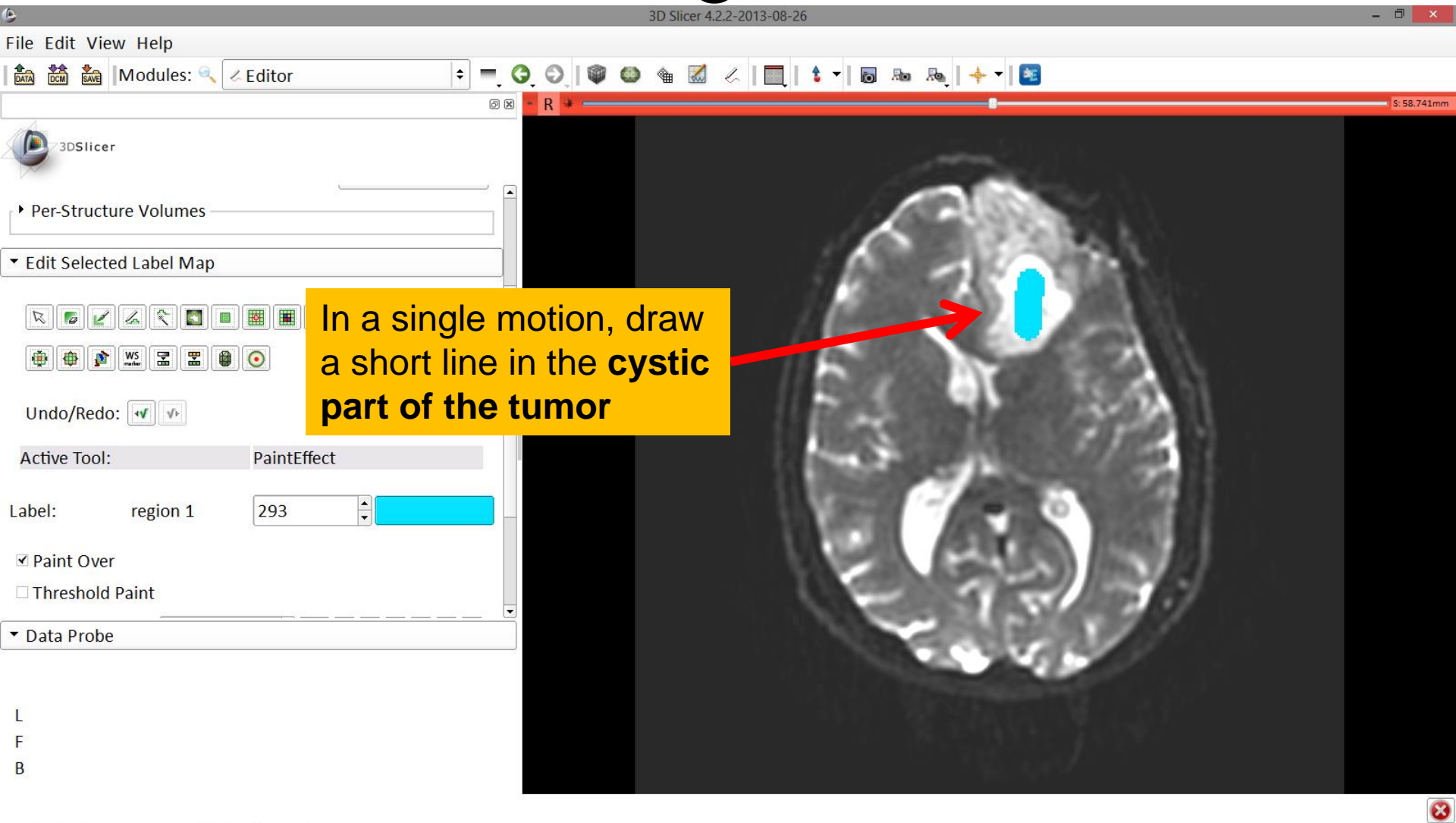
Paint Over
 Threshold Paint

Data Probe

L
F
B

Scroll down the **Editor** module and choose **color #293** for the region 1 label

Tumor Segmentation



Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

DATA DC

Per

▼ Edit Selected Label Map

Undo/Redo: [undo] [redo]

Active Tool: PaintEffect

Label: mass 7 [color swatch]

Paint Over

Threshold Paint

▼ Data Probe

L
F
B

S: 58.741mm

Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Per-Structure Volumes

Edit Selected Label Map

Select color #295 for region 3 and draw a circle around the tumor

Active Tool: PaintEffect

Label: region 3 295

Paint Over

Threshold Paint

Data Probe

L

F

B

Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Per-Structure Volumes

Edit Selected Label Map

Active Tool: PaintEffect

Label: region 3 295

Paint Over

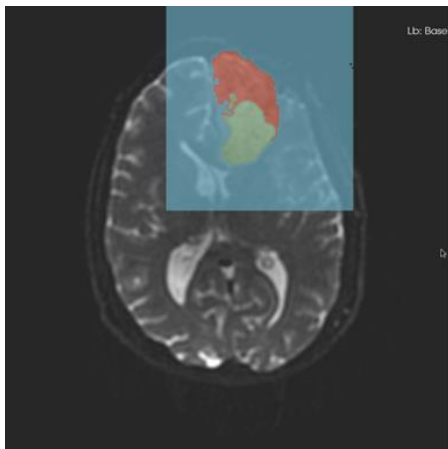
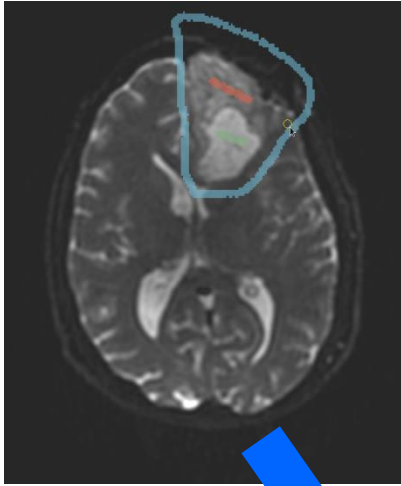
Threshold Paint

Data Probe

L
F
B

Select the **GrowCutEffect** tool

Grow Cut Segmentation



- The **Grow Cut Segmentation** method is a competitive region growing algorithm using Cellular Automata.
- The algorithm performs multi-label image segmentation using a set of user input scribbles.
- V. Vezhnevets, V. Konouchine. "Grow-Cut" - Interactive Multi-Label N-D Image Segmentation". *Proc. Graphicon*. 2005 . pp. 150–156.

Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Edit Selected Label Map

Undo/Redo: [Undo] [Redo]

Active Tool: GrowCutEffect

Label: region 3 295

Run the GrowCut segmentation on the current label map. This will use your current segmentation as an example to fill in the rest of the volume

Apply

▼ Data Probe

L
F
B

R S: 58.741mm

Click **Apply** to apply the **GrowCutEffect** segmentation algorithm

Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Slicer displays the results from the segmentation

Active Tool: GrowCutEffect

Label: region 3 295

Run the GrowCut segmentation on the current label map. This will use your current segmentation as an example to fill in the rest of the volume.

Apply

▼ Data Probe

L
F
B

Solid part

Cystic part

S: 58.741mm

Tumor Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Scroll up the **Editor** menu and select the tab **Per-Structure Volumes**. Then click **Split Merge Volume**

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label Set...

Per-Structure Volumes

Add Structure **Split Merge Volume**

Delete Structures Merge All Merge And Build

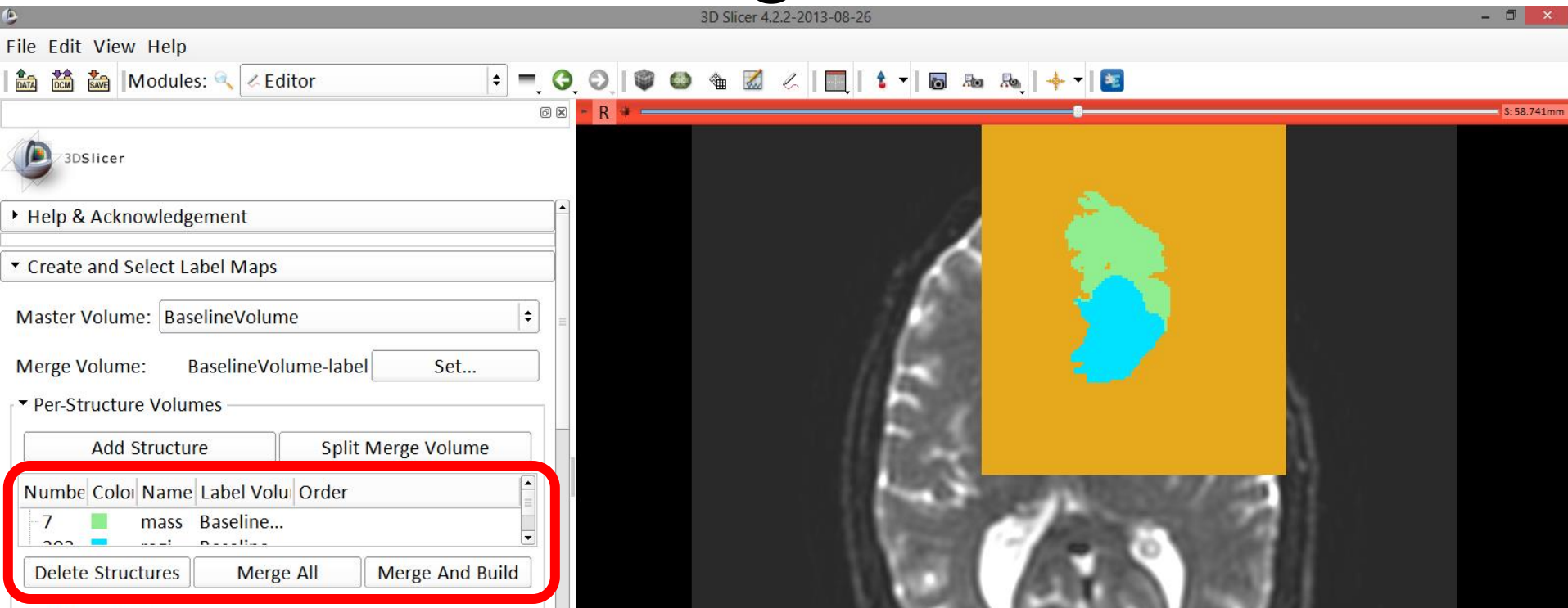
Replace Models

Data Probe

L
F
B

S: 58.741mm

Tumor Segmentation



The label map **BaselineVolume-label** has been split into three volumes:

- BaselineVolume-mass-label**: solid part of the tumor
- BaselineVolume-region_1-label**: cystic part of the tumor
- BaselineVolume-region_3-label**: surrounding structures

Tumor Segmentation

The image shows the 3D Slicer software interface. The main window displays an axial MRI slice of a brain with a segmented tumor region highlighted in green and blue. A red arrow points from the 'Data' module in the 'Modules' menu to the segmented tumor. A yellow callout box contains the text: "Click on the Modules menu and select the Module **Data**".

3D Slicer 4.2.2-2013-08-26

File Edit View Help

DATA DCM SAVE Modules:

3DSlicer

Help & Acknowledgements

Create and Select Label M

Master Volume: Baseline

Merge Volume: Baseline

Per-Structure Volumes

Add Structure

Number	Color	Name	Label
7	Green	mass	Base
8	Blue		

Delete Structures

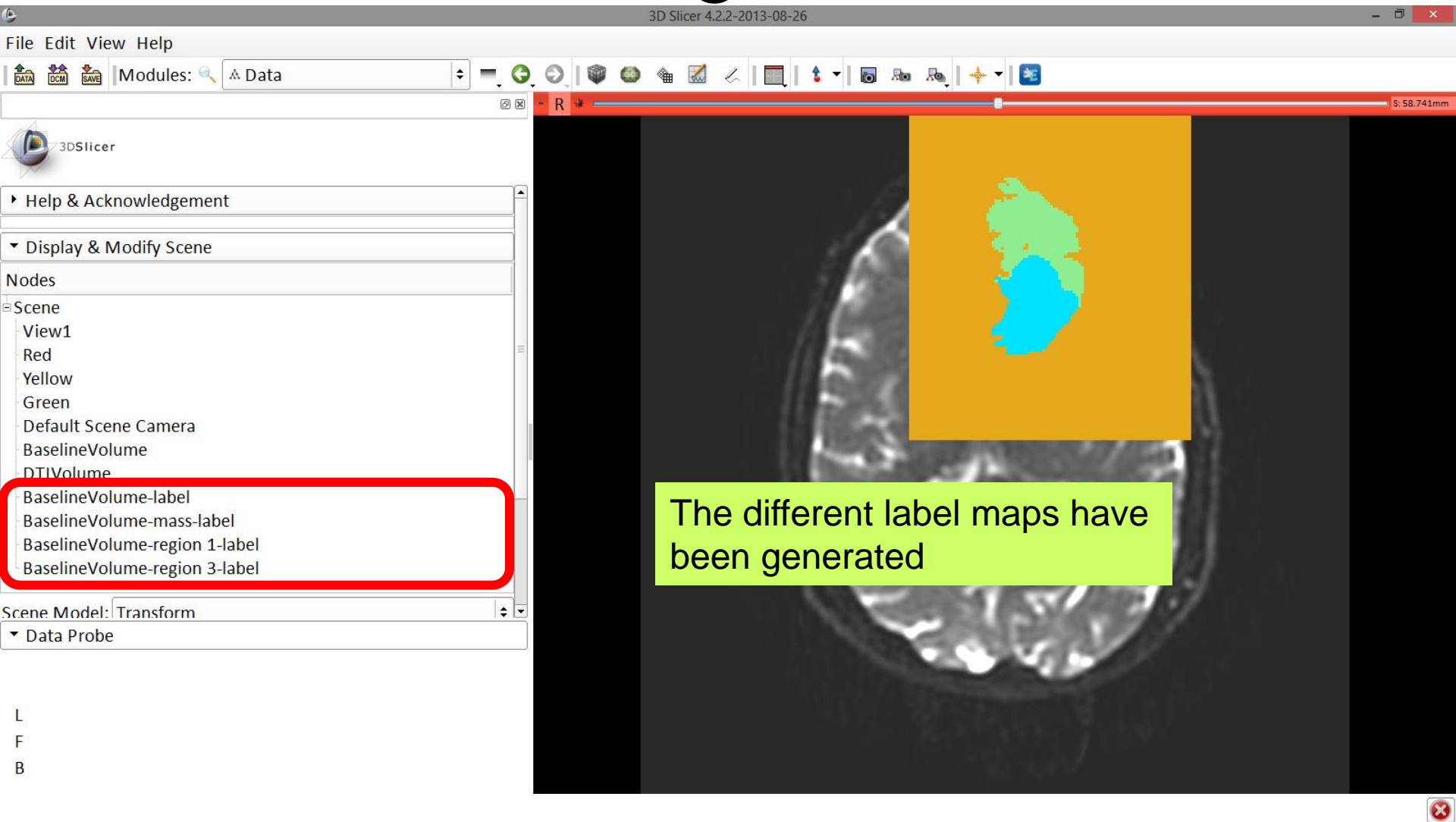
Replace Models

Data Probe

All Modules

- Legacy
- Testing
- Work in Progress
- Data**
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Transforms
- View Controllers
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- Welcome to Slicer
- Wizards
- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
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- Endoscopy
- Utilities
- Developer Tools

Tumor Segmentation



Ventricles Segmentation

The image shows the 3D Slicer software interface. The 'Modules' menu is open, and the 'Editor' module is highlighted with a red arrow. A yellow callout box with the text 'Go back to the Editor module' is positioned over the main 3D view, which displays a brain MRI slice with segmented ventricles in green and blue. The interface includes a top menu bar (File, Edit, View, Help), a toolbar, and a left sidebar with 'Nodes' and 'Scene Model' panels.

Ventricles Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label Set...

Per-Structure Volumes

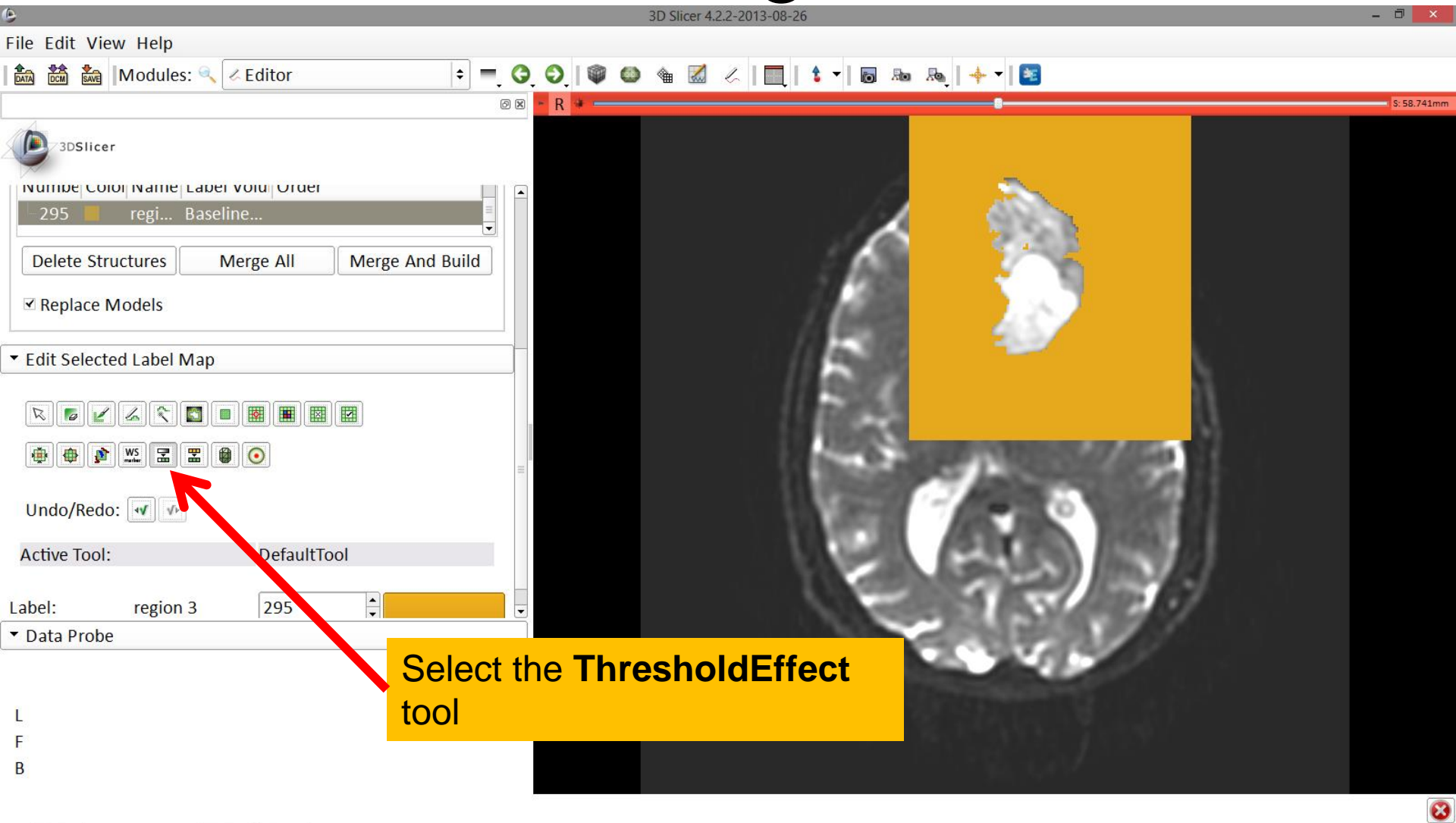
Add Structure Split Merge Volume

Number	Color	Name	Label Volume	Order
295	Yellow	regi...	Baseline...	

Delete Structures Merge All Merge And Build

Select the volume **BaselineVolume-region_3-label** so that it is highlighted and that the yellow region is visible in the viewer

Ventricles Segmentation



Ventricles Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Active Tool: ThresholdEffect

Label: region 3 295

Threshold Range: 1700.00 18197.00

Use For Paint

Apply

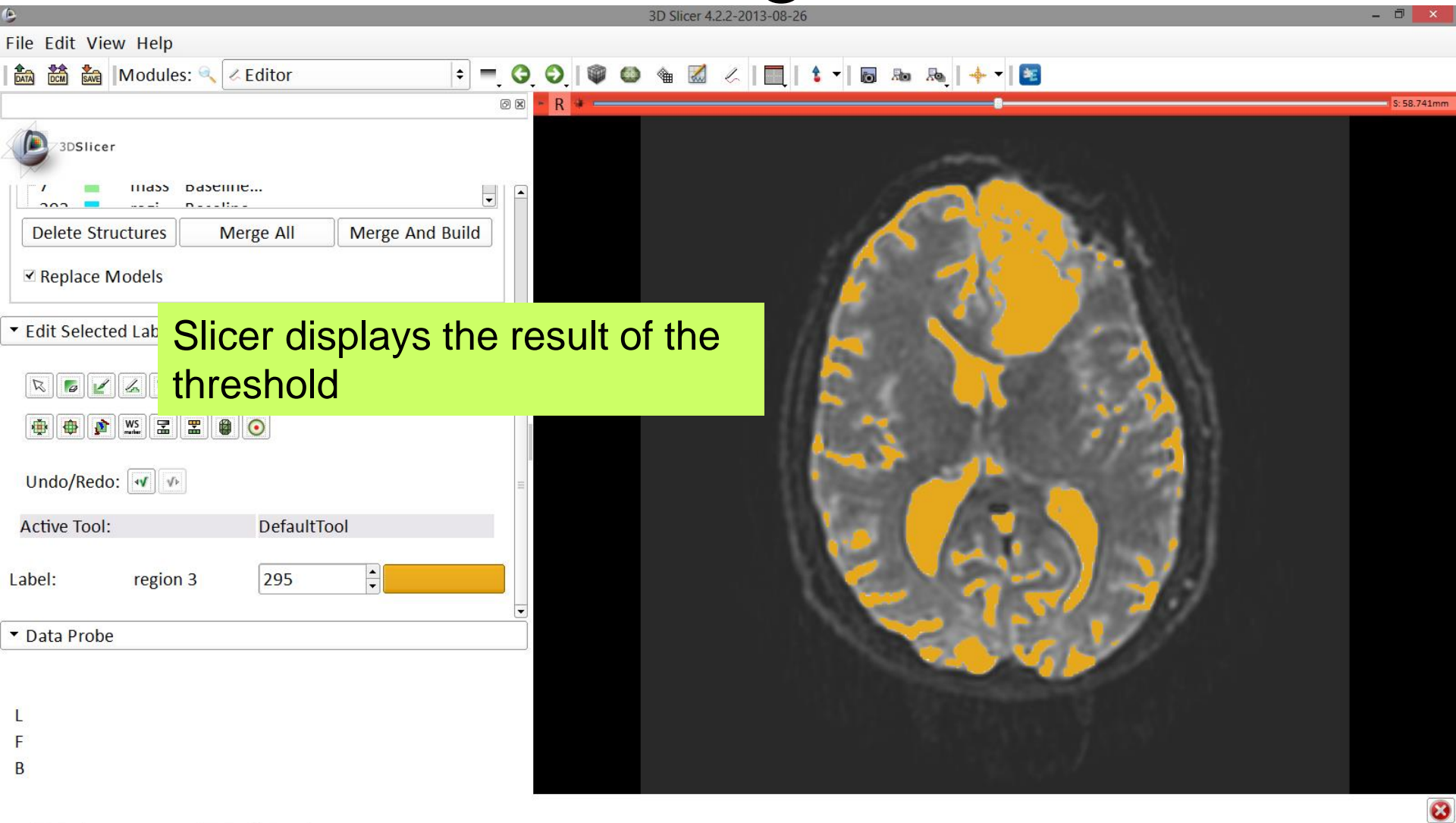
▼ Data Probe

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F
B

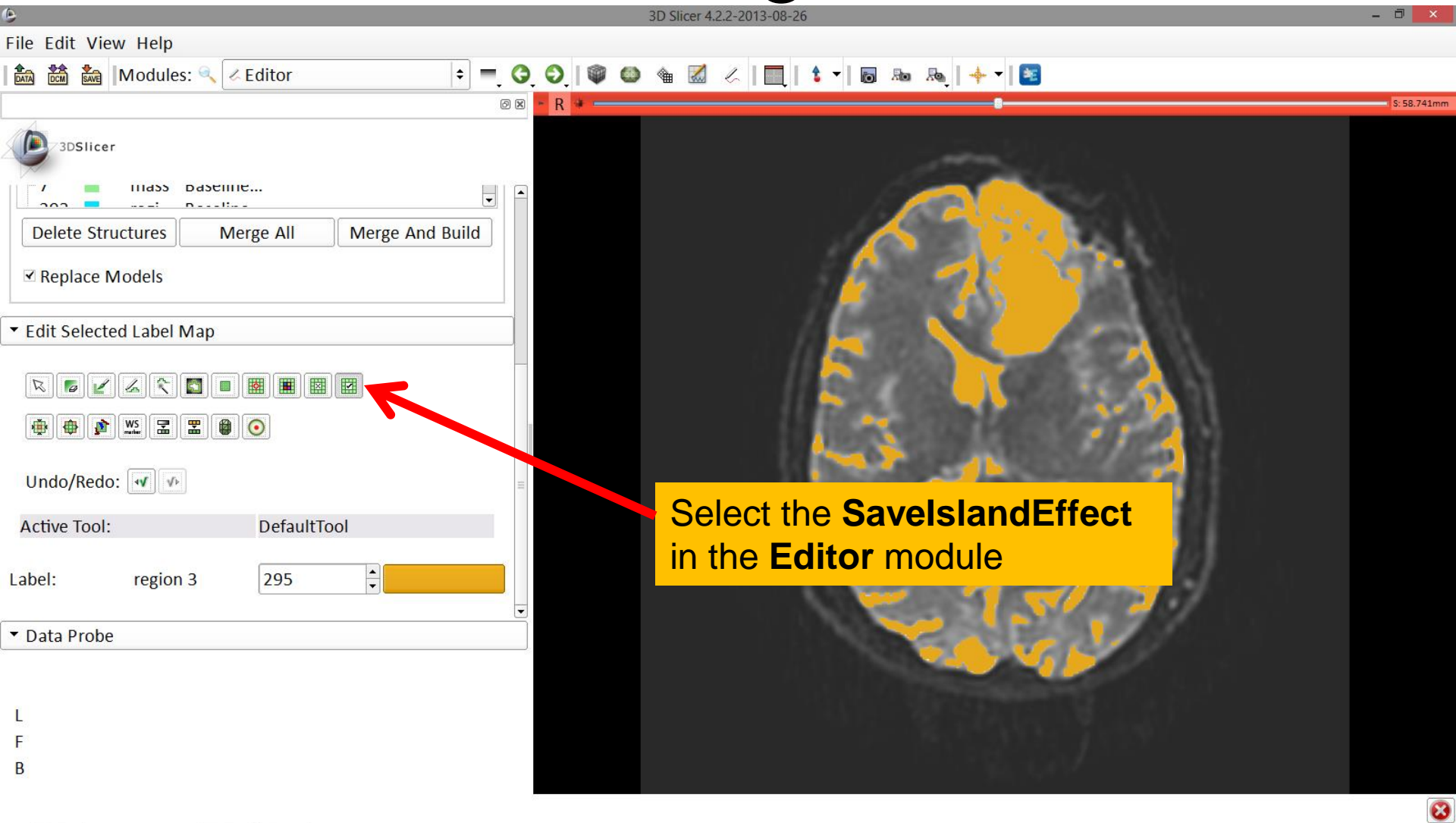
S: 58.741mm

Scroll down the **Editor** module and set the lower **Threshold Range** to **1700** and click **Apply**

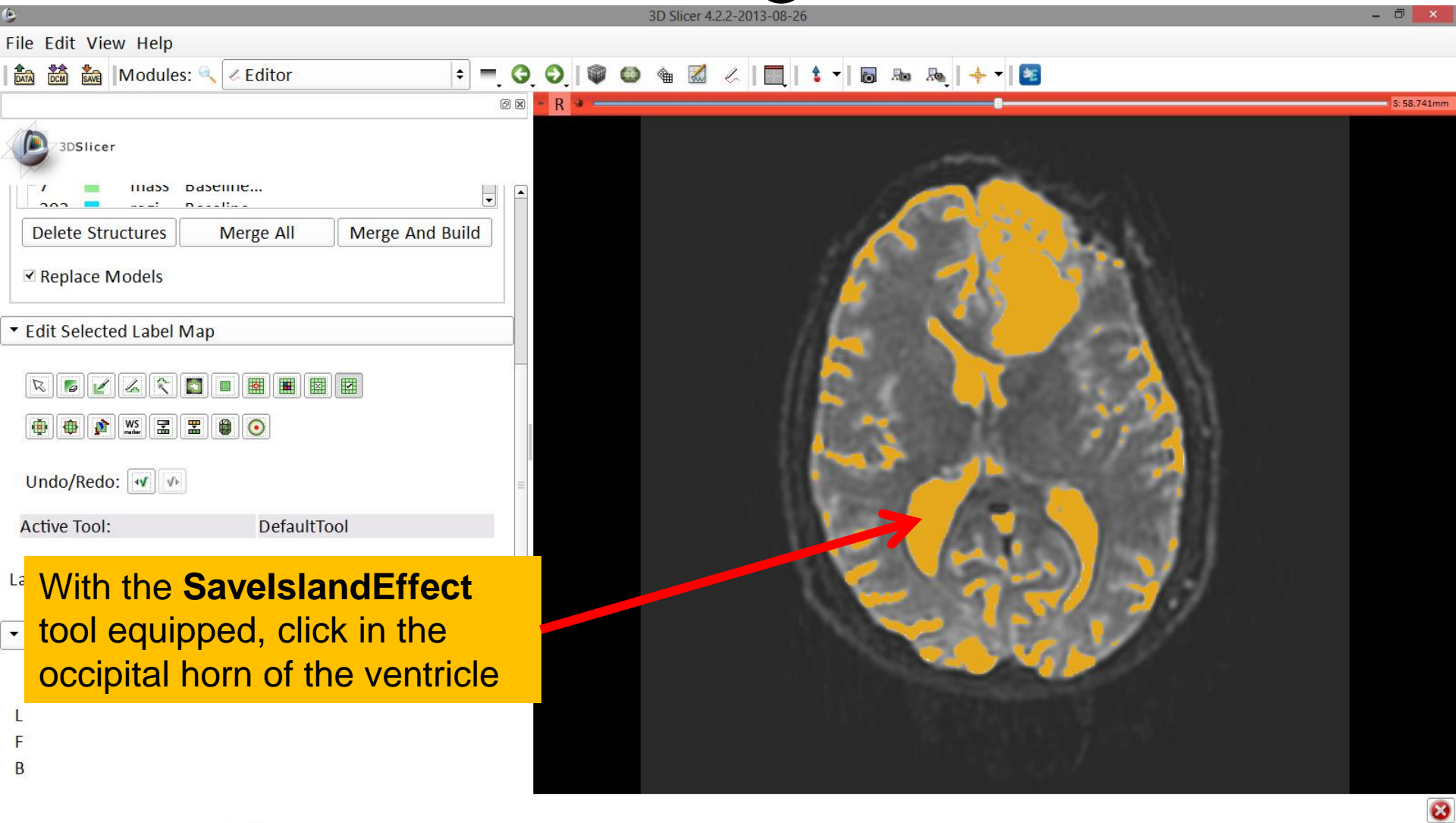
Ventricles Segmentation



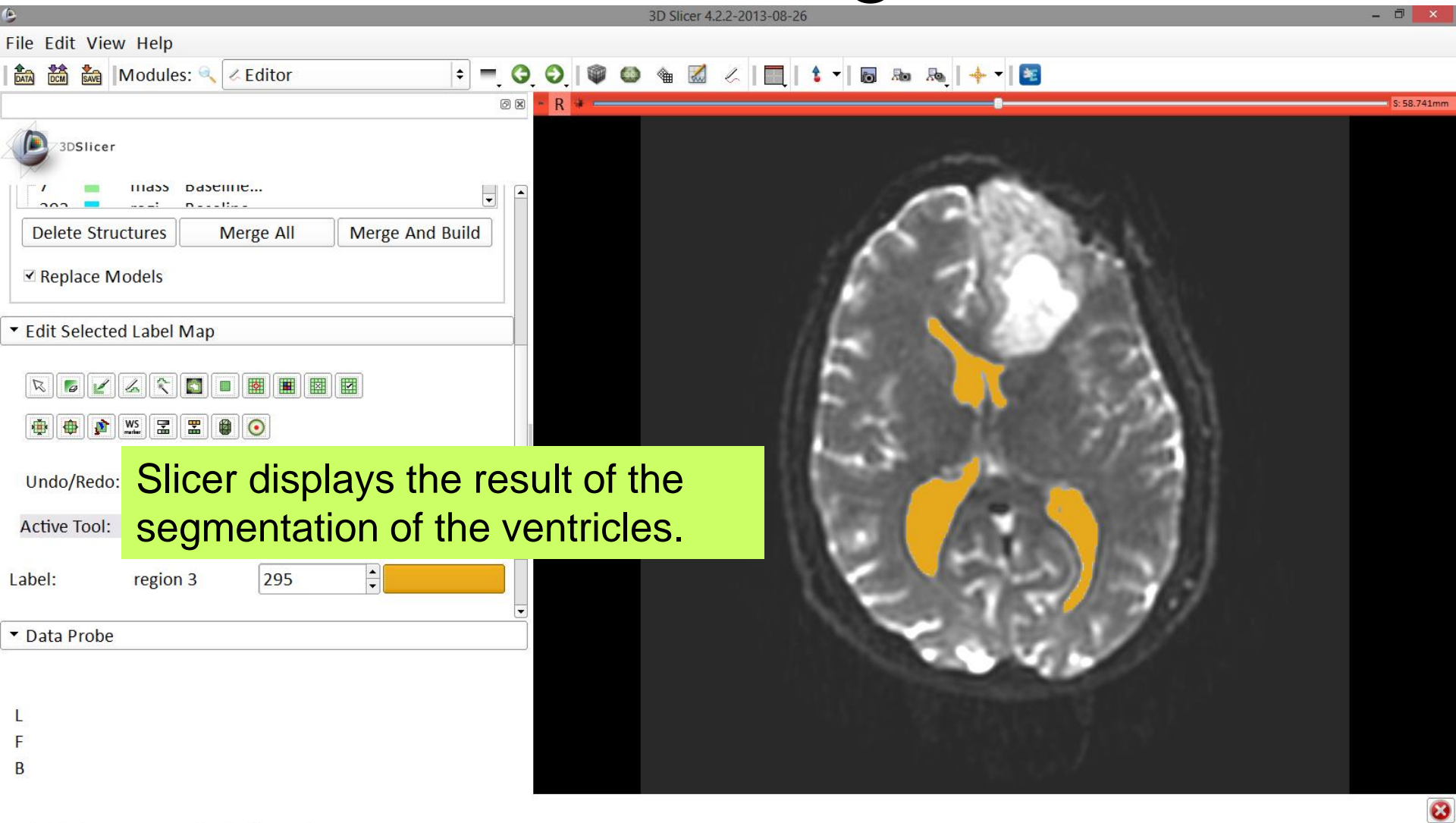
Ventricles Segmentation



Ventricles Segmentation



Final Result of Segmentation



Final Result of Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: BaselineVolume

Merge Volume: BaselineVolume-label Set...

Per-Structure Volumes

Add Structure Split Merge Volume

Number	Color	Name	Label Volume	Order
7	Green	mass	Baseline...	
8	Blue	ventricle	Baseline...	

Delete Structures Merge All Merge And Build

Replace Models

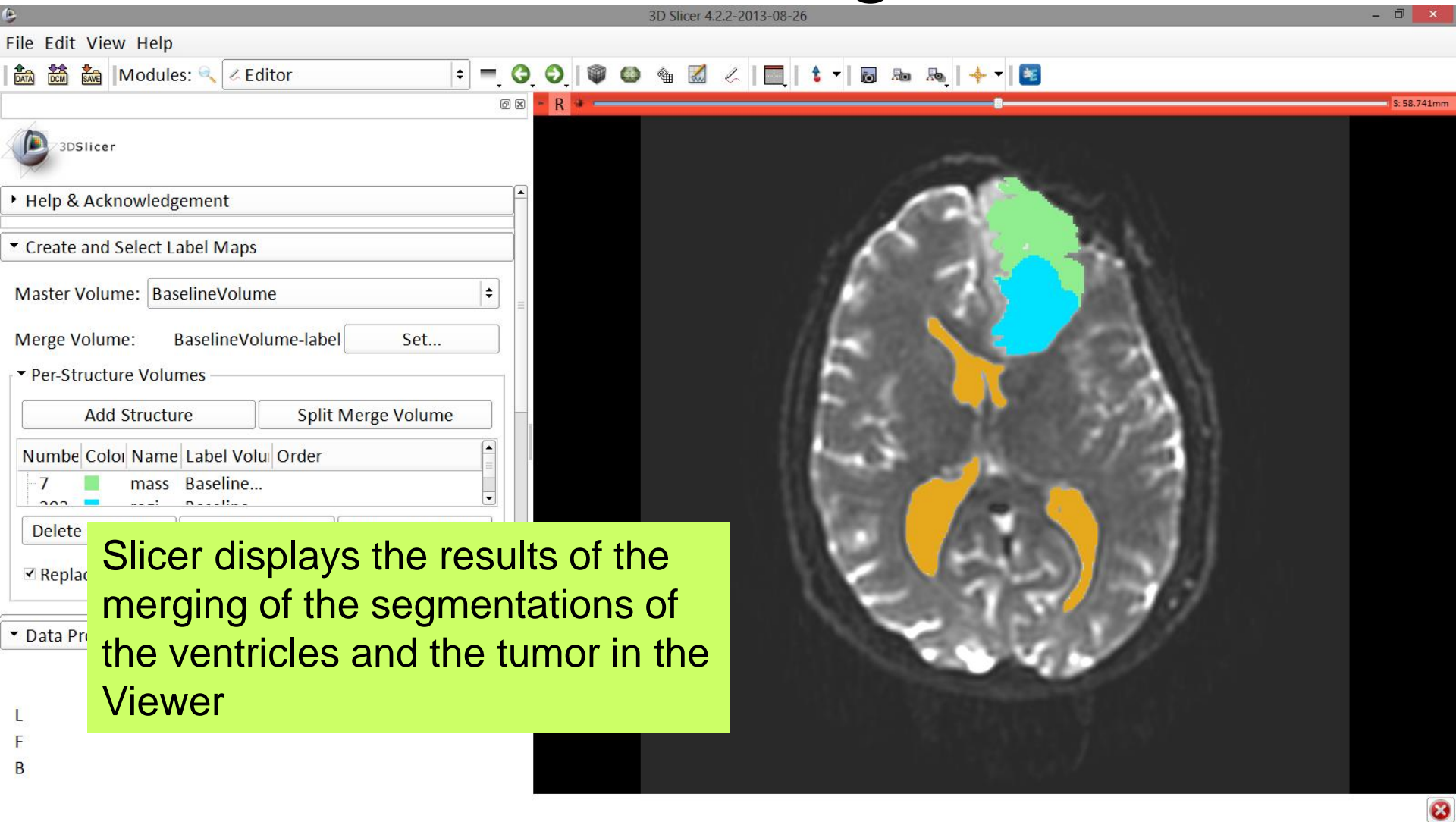
Data Probe

L
F
B

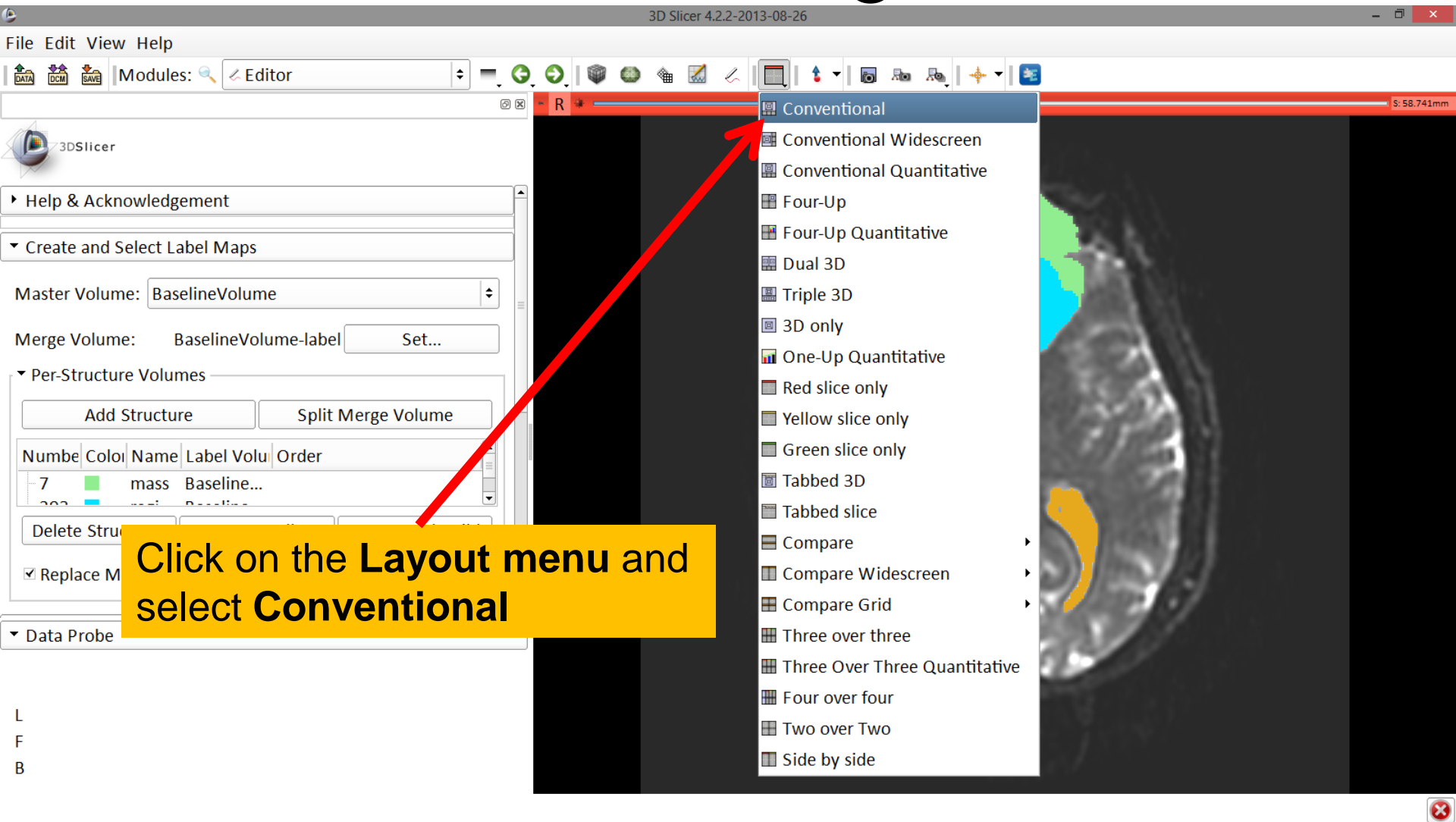
S: 58.741mm

Scroll back up and click on **Merge and Build** to merge the different label maps, and generate the 3D models of the tumor and ventricles using a Marching Cubes algorithm

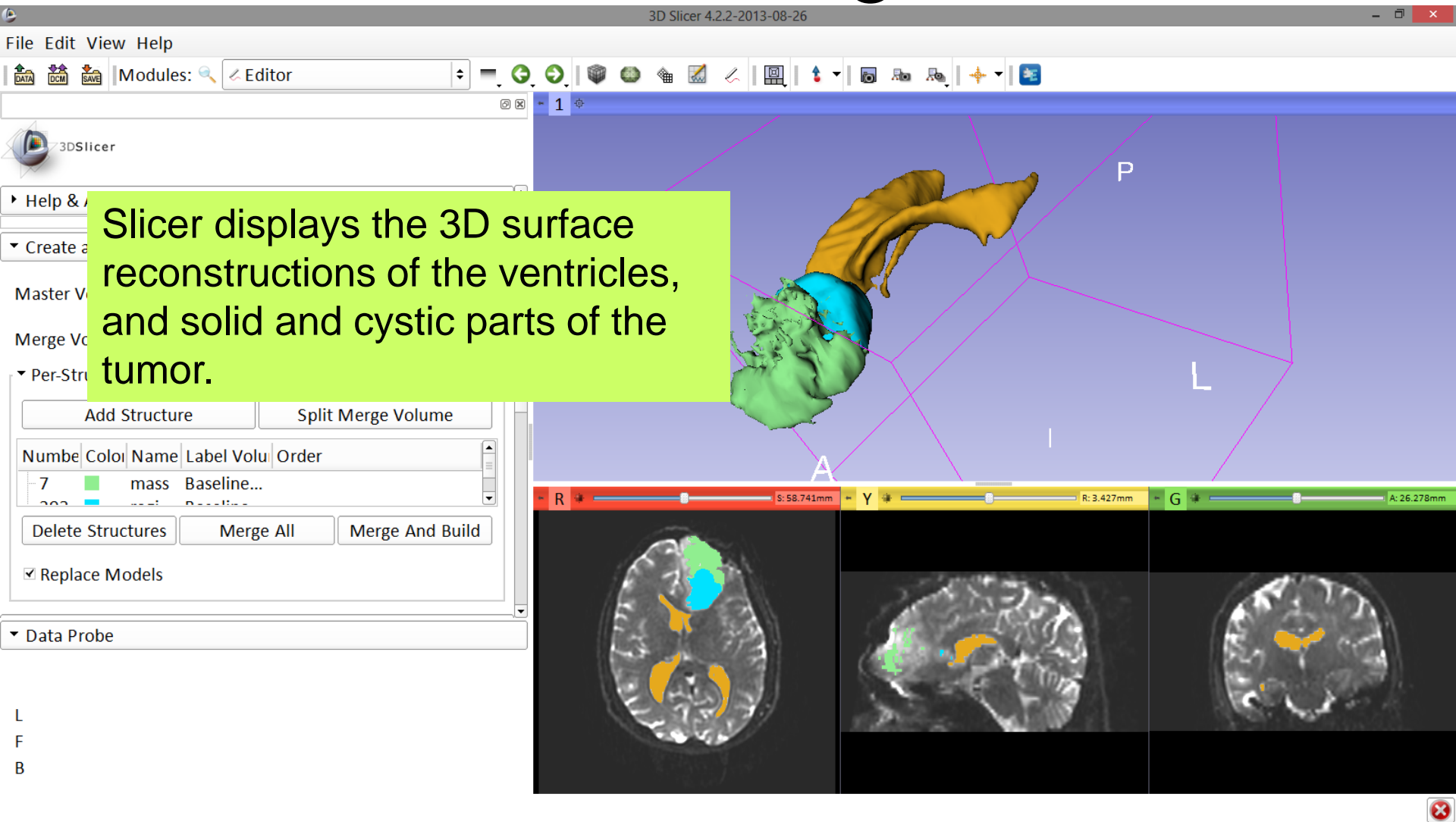
Final Result of Segmentation



Final Result of Segmentation

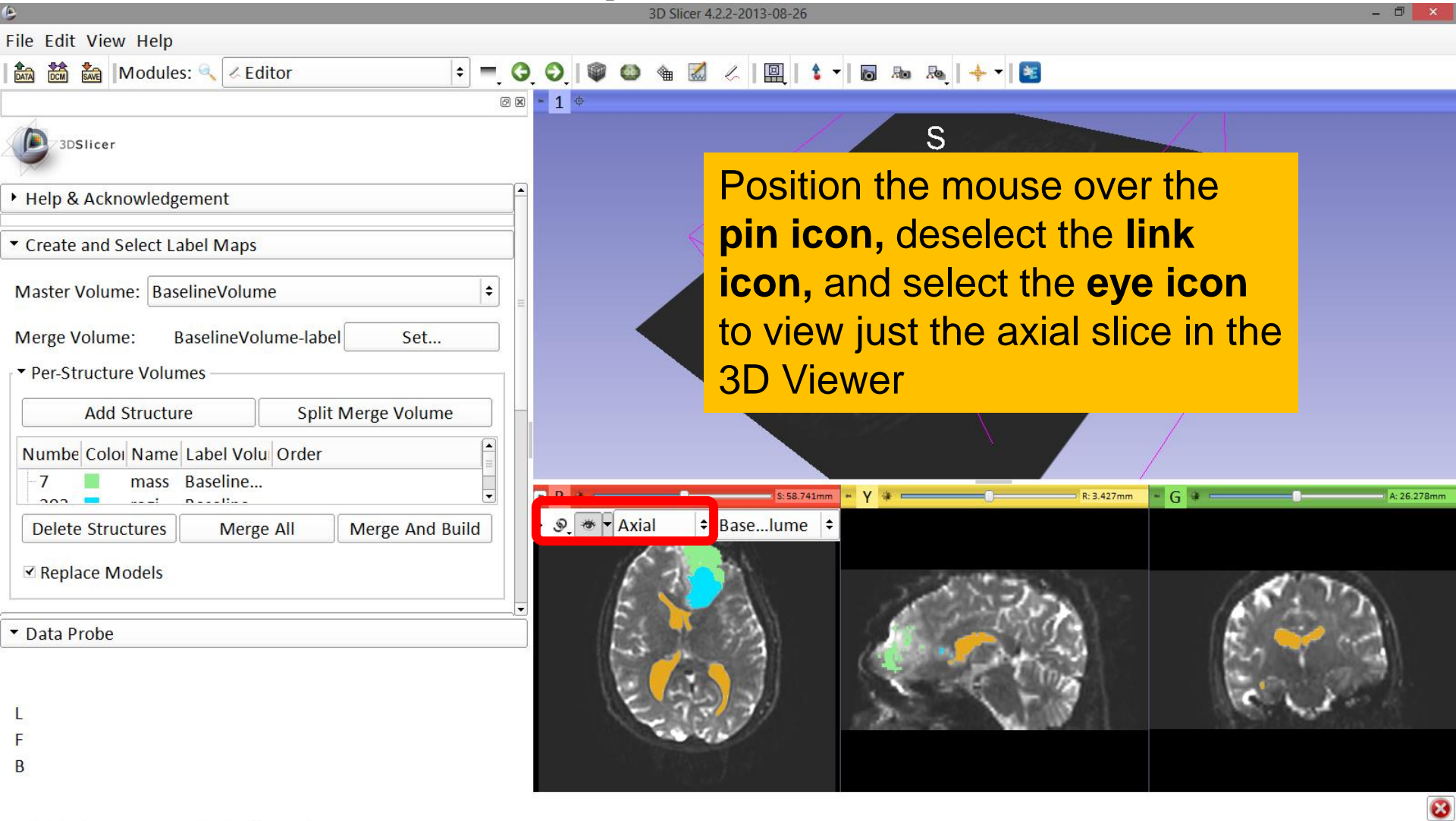


Final Result of Segmentation

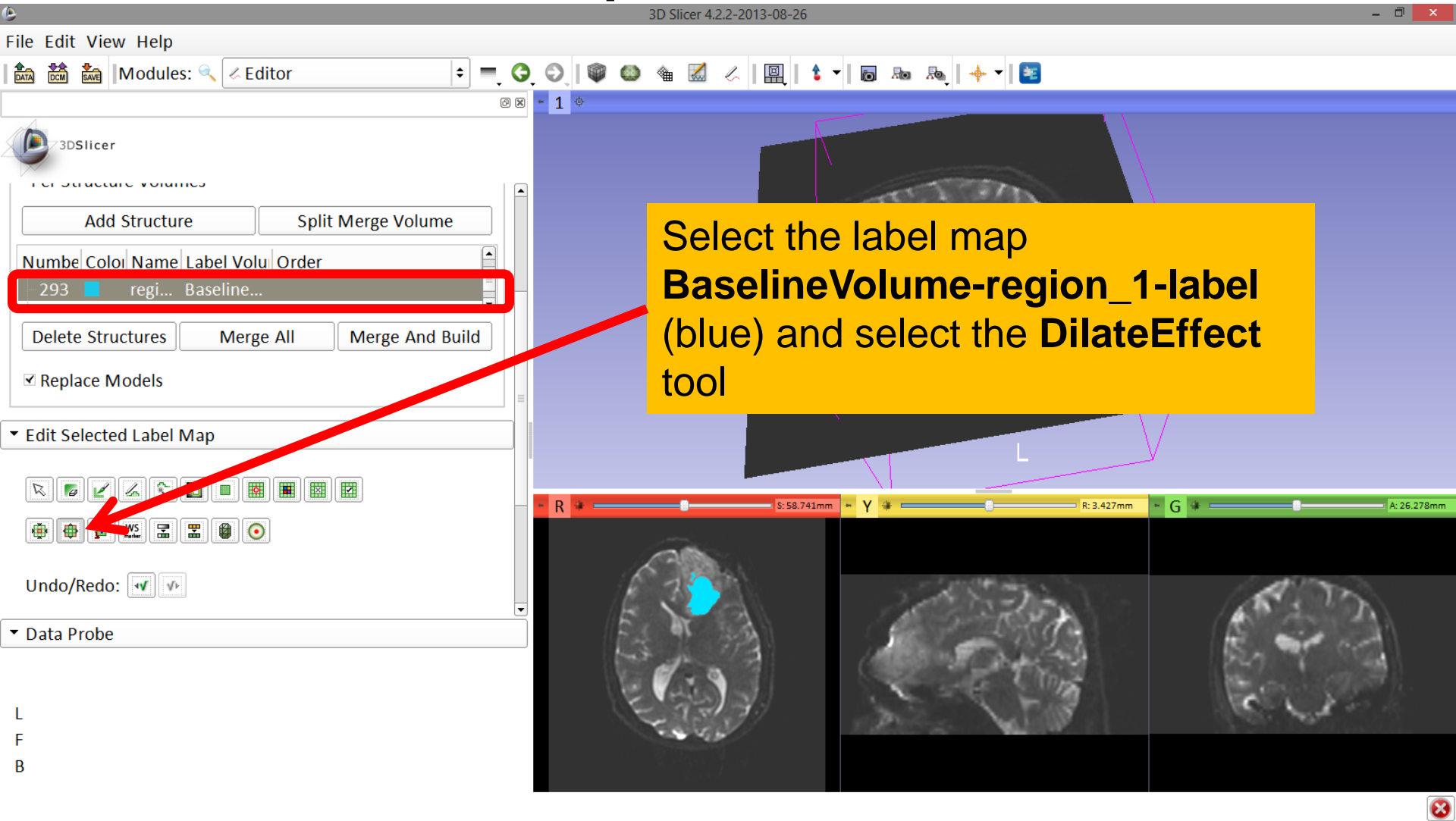


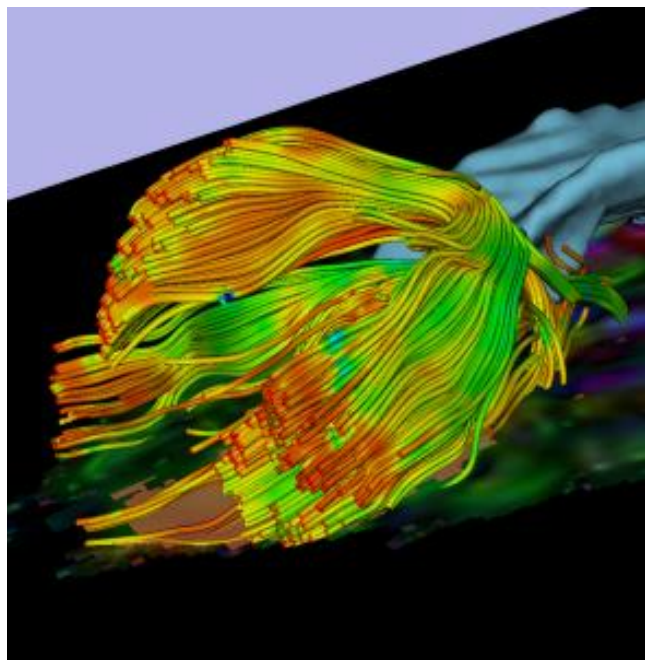
Slicer displays the 3D surface reconstructions of the ventricles, and solid and cystic parts of the tumor.

Definition of peri-tumoral volume



Definition of peri-tumoral volume





Part 2: Tractography exploration of peri- tumoral white matter fibers

Definition of peri-tumoral volume

The screenshot displays the 3D Slicer software interface. The top menu bar includes 'File', 'Edit', 'View', and 'Help'. Below it is a toolbar with various icons. The main window shows a 3D view of a brain slice with a yellow tumor and a blue highlighted region. A red arrow points from the 'Apply' button in the 'DilateEffect' tool panel to the blue region. The tool panel on the left shows 'Label: region 1' with a value of '293', radio buttons for 'Eight Neighbors' and 'Four Neighbors', and a red-bordered 'Apply' button. The bottom of the interface shows three orthogonal views (axial, sagittal, and coronal) of the brain slice.

With the **DilateEffect** tool equipped, click on the cystic part of the tumor in the axial slice viewer once, then select **Apply 3 times** to generate the peritumoral volume

Label: region 1 293

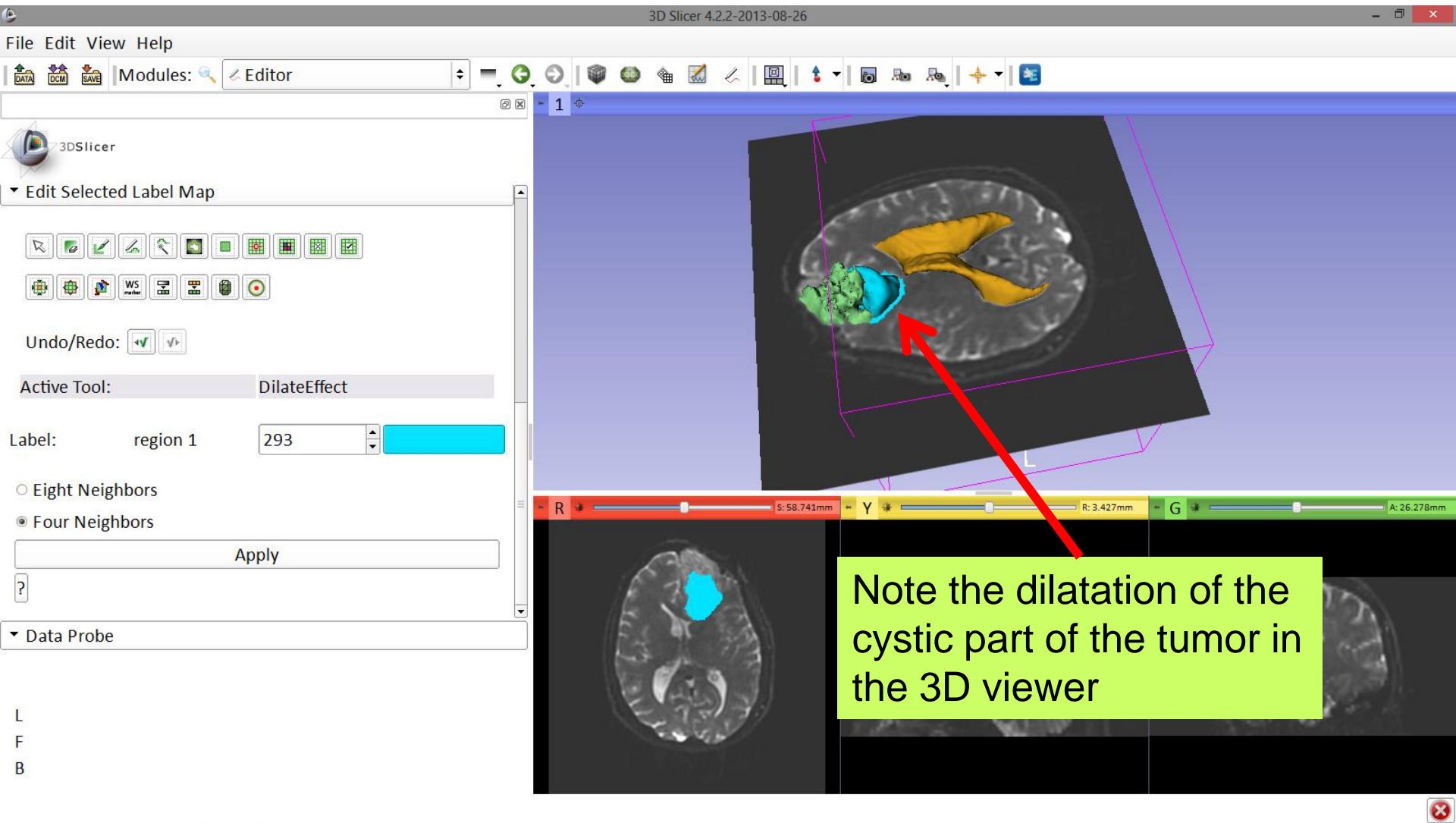
Eight Neighbors

Four Neighbors

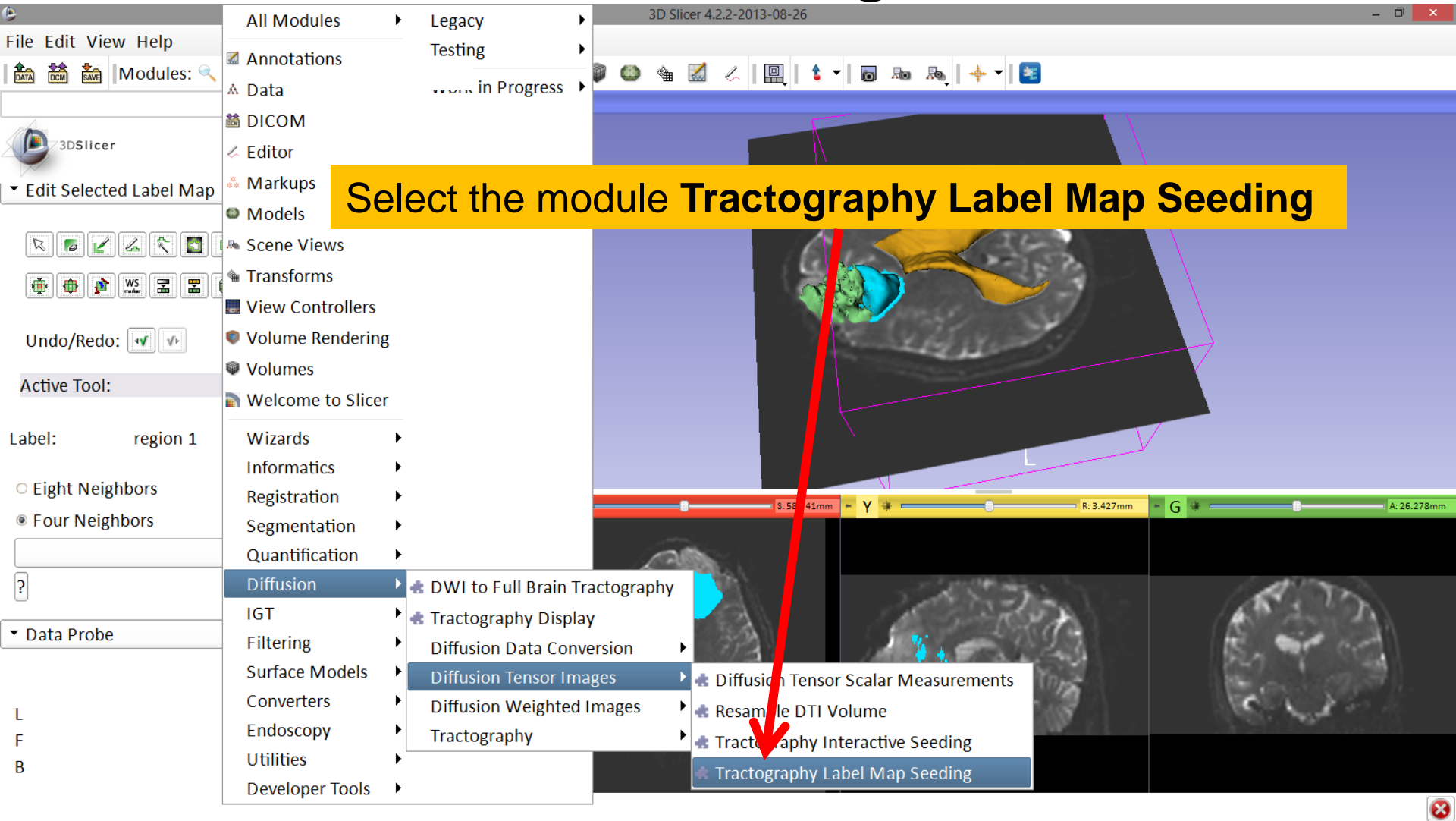
▼ Data Probe

L
F
B

Definition of DTI volume



Final Result of Segmentation



Final Result of Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Tractography Label Map Seeding

3DSlicer

Help & Acknowledgement

Tractography Label Map Seeding

Parameter set: Tractography Label Map Seeding

IO

Input DTI Volume DTIVolume

Input Label Map BaselineVolume-region 1-label

Output Fiber Bundle newFiberBundle

Seed Placement Options

Use Index Space

Seed Spacing 2.00

Random Grid

Status: Idle

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

- I/O: Set the following input and output volume:
Input DTI Volume: DTIVolume
Input Label Map: BaselineVolume-region_1-label
Output Fiber Bundle: Create and rename newFiberBundle

Final Result of Segmentation

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Tractography Label Map Seeding

3DSlicer

Help & Acknowledgement

Use Index Space

Seed Spacing 2.00

Random Grid

Linear Measure Start Threshold 0.3

Tractography Seeding Parameters

Minimum Path Length 20.00

Maximum Length 800.00

Stopping Criteria LinearMeasure FractionalAnisotropy

Stopping Value 0.15

Stopping Track Curvature 0.7

Integration Step Length(mm) 0.5

Label definition

Seeding label 293

Status: Idle

Restore Defaults AutoRun

Cancel Apply

Data Probe

1

A: 26.278mm

Apply

Scroll down and set the following values:

- **Seed Placement Options:**
Check **Use Index Space**

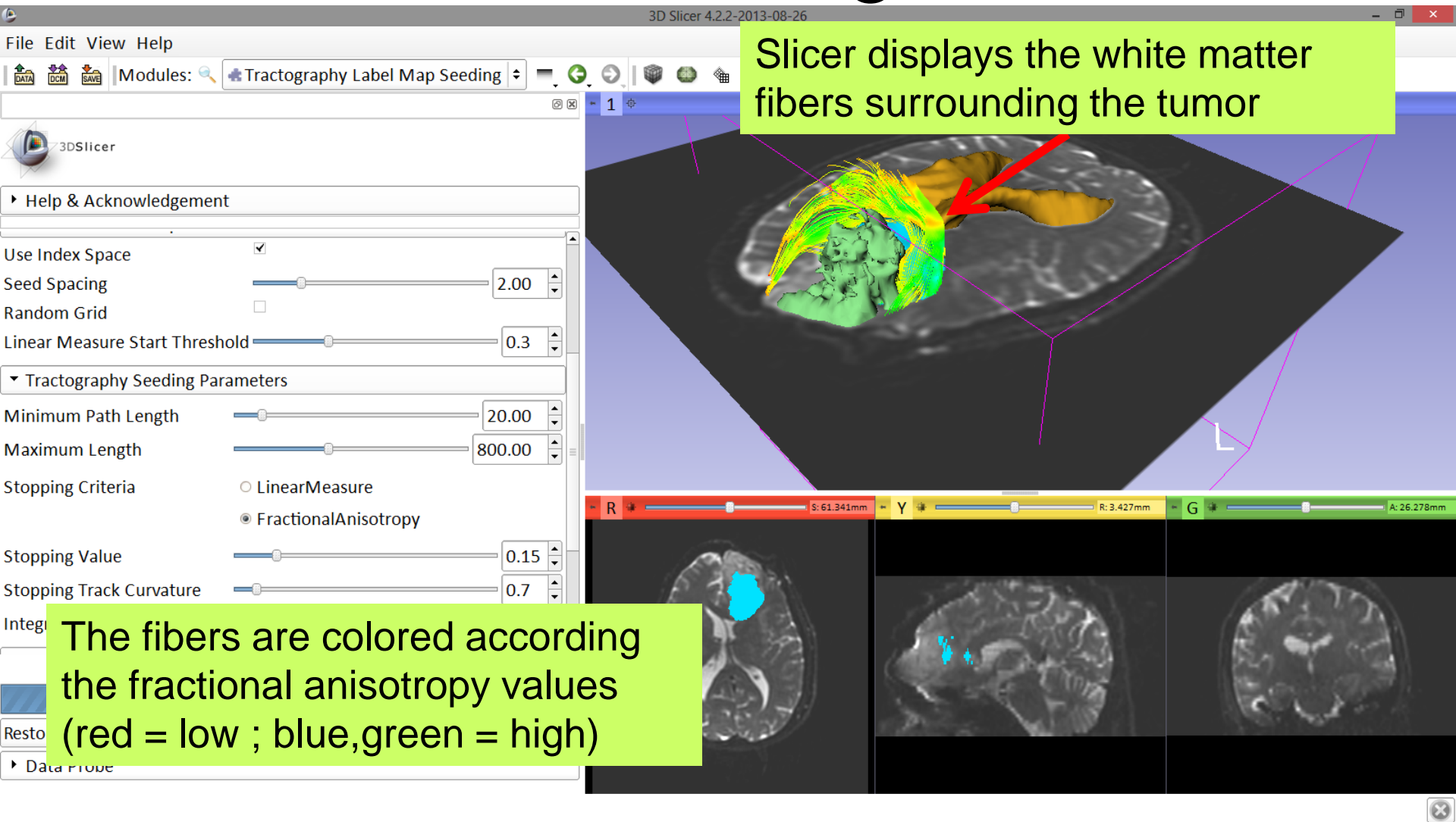
- **Stopping Value**

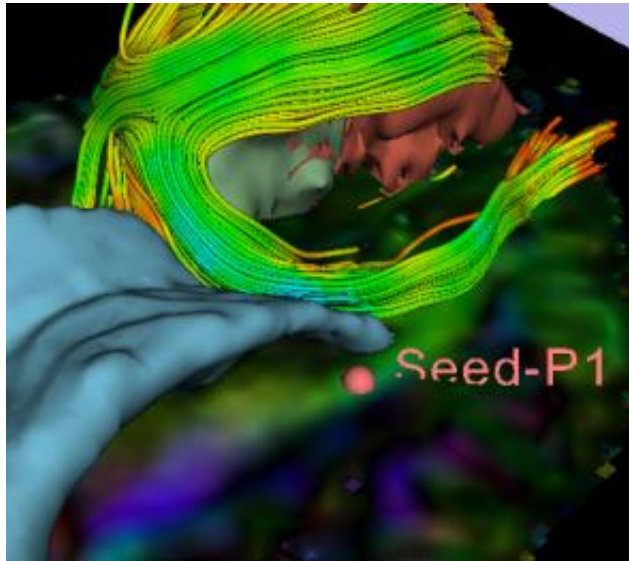
Set the FA threshold to 0.15

- **Label Definition:**

Enter Seeding Label **293**, and
Click on **Apply**

Final Result of Segmentation





Part 4: Tractography exploration of the ipsilateral and contralateral side

Tractography on-the-fly

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules:

- All Modules
 - Legacy
 - Testing
 - Work in Progress
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- DICOM
- Editor
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- Transforms
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- Welcome to Slicer
- Wizards
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- Diffusion**
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 - Diffusion Tensor Scalar Measurements
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 - Tractography Interactive Seeding**
 - Tractography Label Map Seeding
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Use Index Space

Seed Spacing

Random Grid

Linear Measure Start Thresh

Tractography Seeding Parameters

Minimum Path Length

Maximum Length

Stopping Criteria

Stopping Value

Stopping Track Curvature

Integration Step Length(mm)

Restore Defaults AutoRun

Data Probe

R S: 61.341mm Y R: 3.427mm G A: 26.278mm

Click on the **Modules** menu and select the module **Tractography Interactive Seeding**

Tractography on-the-fly

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Tractography Interactive Seeding

3DSlicer

Help & Acknowledgement

IO

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

IO

Input DTI Volume: DTIVolume

Input Fiducials, Model or Label Map: Select a MarkupsFiducial

Output Fiber Bundle: Select a FiberBundle

Enable Seeding Tracts:

Seed Placement Options

Fiducial Region Size: 2.50mm

Fiducial Seeding Step Size: 1.00mm

Seed Selected Fiducials:

Max Number of Seeds: 100

Data Probe

Position the mouse over the **pin icon** in the axial slice viewer and change the volume to **DTIVolume**

None
BaselineVolume
DTIVolume
BaselineVolume-label
BaselineVolume-mass-label
BaselineVolume-region 1-label
BaselineVolume-region 3-label
Rename current Volume

Tractography on-the-fly

Select the **Fiducial icon**, and position it next to the cystic part of the tumor by clicking near it in the 3D viewer

Input DTI Volume: DTIVolume
Input Fiducials, Model or Label Map: Select a MarkupsFiducial
Output Fiber Bundle: Select a FiberBundle
Enable Seeding Tracts:
Seed Placement Options
Fiducial Region Size: 2.50mm
Fiducial Seeding Step Size: 1.00mm
Seed Selected Fiducials:
Max Number of Seeds: 100
Data Probe

Tractography on-the-fly

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Tractography Interactive Seeding

3DSlicer

Help & Acknowledgement

IO

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

IO

Input DTI Volume: DTIVolume

Input Fiducials, Model or Label Map: F

Output Fiber Bundle: FiberBundle_F

Enable Seeding Tracts:

Seed Placement Options

Fiducial Region Size: 2.50mm

Fiducial Seeding Step Size: 1.00mm

Seed Selected Fiducials:

Max Number of Seeds: 100

Data Probe

Set Input DTI Volume to **DTIVolume**
Set Fiducial List or Model to **F**
Set Output Fiber Bundle to **Create new Fiber Bundle**

Tractography on-the-fly

3D Slicer 4.2.2-2013-08-26

File Edit View Help

Modules: Tractography Interactive Seeding

3DSlicer

Fiducial Region Size 2.500mm

Fiducial Seeding Step Size 1.00mm

Seed Selected Fiducials

Max Number of Seeds 100

Tractography Seeding Parameters

Minimum Path Length 10.000mm

Maximum Path Length 800.000mm

Stopping Criteria Fractional Anisotropy

Stopping Value 0.150

Stopping Track Curvature 0.700

Integration Step Length 0.500mm

Enabling Options

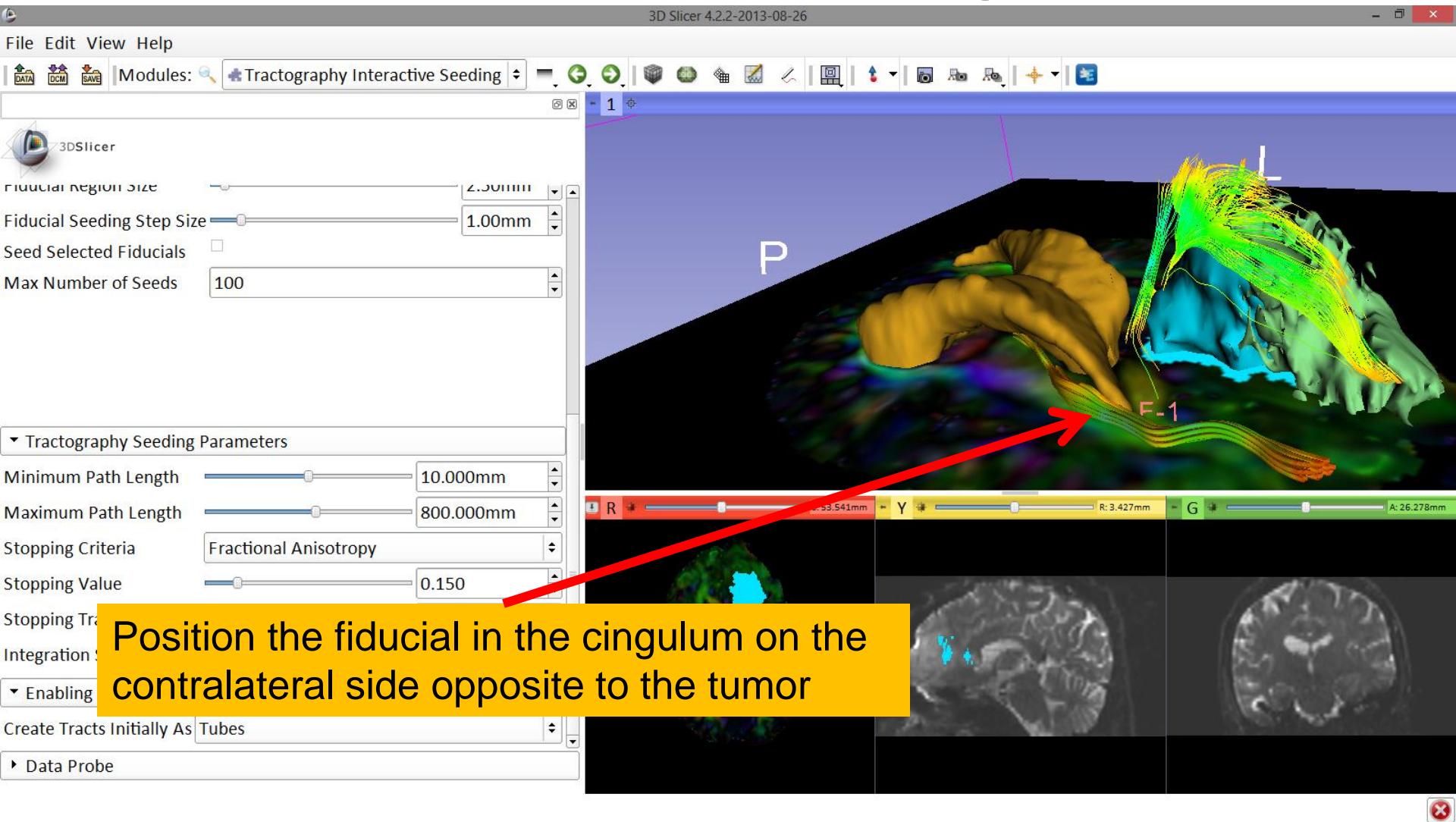
Create Tracts Initially As Tubes

Data Probe

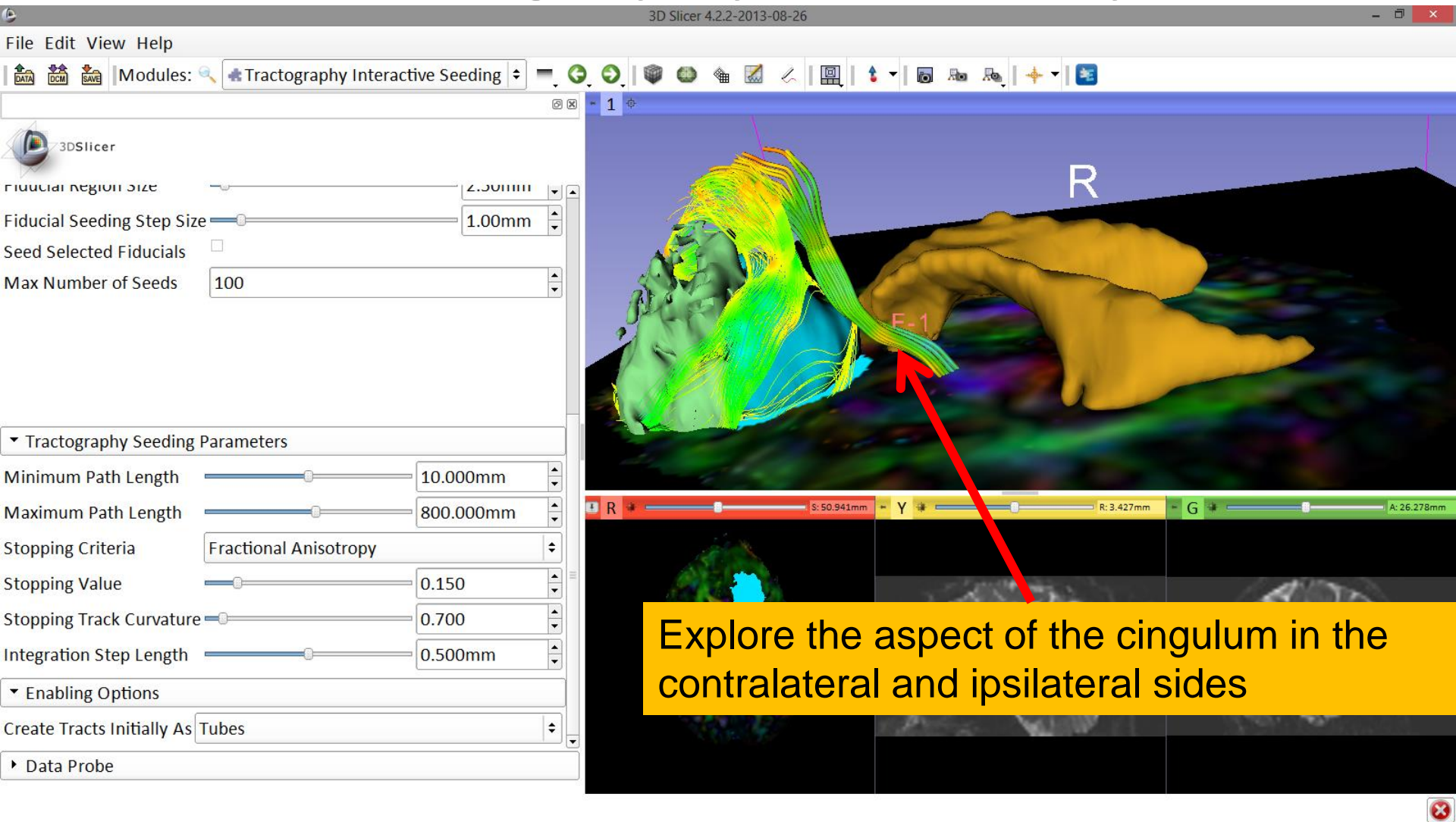
Scroll down the module and set the **Minimum Path Length** to 10.0 mm and the **FA Stopping Value** at 0.15

R S: 53.541mm Y R: 3.427mm G A: 26.278mm

Fiducial Seeding



Tractography on-the-fly



Conclusion

- Fully integrated pipeline for semi-automated tumor segmentation and white matter tract reconstruction
- 3D interactive exploration of the white matter tracts surrounding a tumor (peritumoral tracts) for neurosurgical planning

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