resonint

ilumr - Desktop MRI

User Manual

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1. Introduction

Welcome to the User Manual for the ilumr Educational MRI instrument from Resonint limited. When unpacking please identify all the following components:

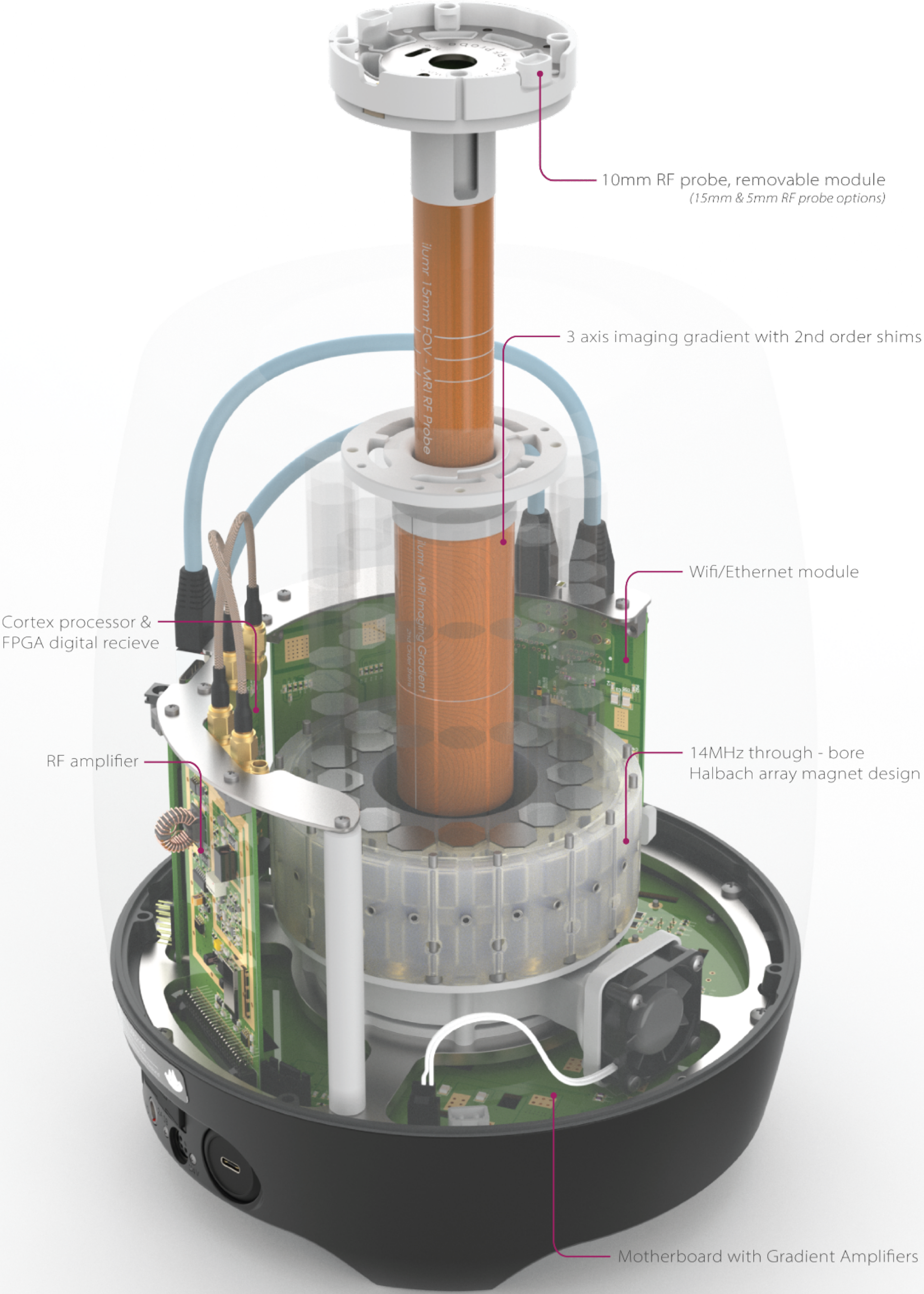
- The ilumr MRI system with Gradient and 10mm RF probe installed
- 120W 24V DC power supply
- Sample depth gauge
- 10x 10mm glass tubes
- 4x 10mm sample holders
- 15mm RF probe (optional extra)
- 15mm air vent disk (optional extra)
- 10x 15mm glass tubes (optional extra)
- 4x 15mm sample holders (optional extra)
- RF probe tuning tool
- Probe insert for fastener removal

1.1 System Components

The ilumr desktop MRI system is fully integrated and contains all the necessary hardware components with the performance required for a complete exploration of NMR & MRI techniques. Below are some of the hardware features of ilumr:

- Halbach design through bore temperature stabilised magnet.
- High performance over-sampling digital receiver providing superb linearity & dynamic range.
- Integrated gradient & shim amplifiers, providing shaped gradient pulses and 2nd order electrical shims.
- Air cooled gradient for optimal system stability.
- Modular RF probe design for customisation.

The diagram on the following page gives an overview of the key building blocks of the ilumr system.


10mm RF probe, removable module
(15mm & 5mm RF probe options)
ilumr 15mm FOV - MRI RF Probe
3 axis imaging gradient with 2nd order shims
ilumr - MRI Imaging Gradient
2nd Order Shims
Wifi/Ethernet module
Cortex processor &
FPGA digital recieve
RF amplifier
14MHz through - bore
Halbach array magnet design
Motherboard with Gradient Amplifiers

1.2 Hardware Specifications

The following table summaries the hardware specifications of the ilumr.

Magnet	
Design	Halbach Array
Field strength	0.33 T (1H 14 MHz)
Temperature control	PID temperature control to 30°C with 0.001 °C resolution
Temperature operating range	Laboratory environment of 15 °C to 25 °C
1H 50% Linewidth	10mm sample volume with shims, < 70 Hz
1H 50% Linewidth	15mm sample volume with shims, < 100 Hz
RF	
Transmit Amplifier	5W 60MHz bandwidth
Receive Preamp	Low Noise, Wideband, Variable 60-80 dB Gain
RF Probe	Solenoid coil 10mm Diameter, Adjustable Tuning/Matching
180 hard pulse minimum width	25 µs
Probe dead time + Preamp recovery time	50 µs
Gradient & Shims	
Gradient Strength	150 mT/m per Channel (X/Y/Z)
Gradient Amplifier	Up to 3A Current-Output per Channel (X/Y/Z)
Shims	First & Second Order (X, Y, Z, Z2, X2Y2, XY, ZX, ZY)
Digital	
Processor	Dual-core ARM Cortex-A9
Memory	1 GB DDR3
Storage	64 GB Internal SD Card
Receive	16-bit 100Msps ADC
RF Transmit	16-bit 100Msps DAC
Gradient/Shim Channels	8
Pulse Sequencer	FPGA, 10 ns timing resolution
Digital Receive Processor	FPGA, 32-bit quadrature output
Connectivity	
WiFi	Dual-band 802.11 a/b/g/n up to 100Mbps
Ethernet	IEEE 802.3 10/100/1000Mbps
Other	
Power Supply	DC, 24V 120W
System Weight	8.9 kg
Dimensions	245 x 245 x 320 mm
External I/O's	2 inputs, 4 outputs, logic level 3.3V.

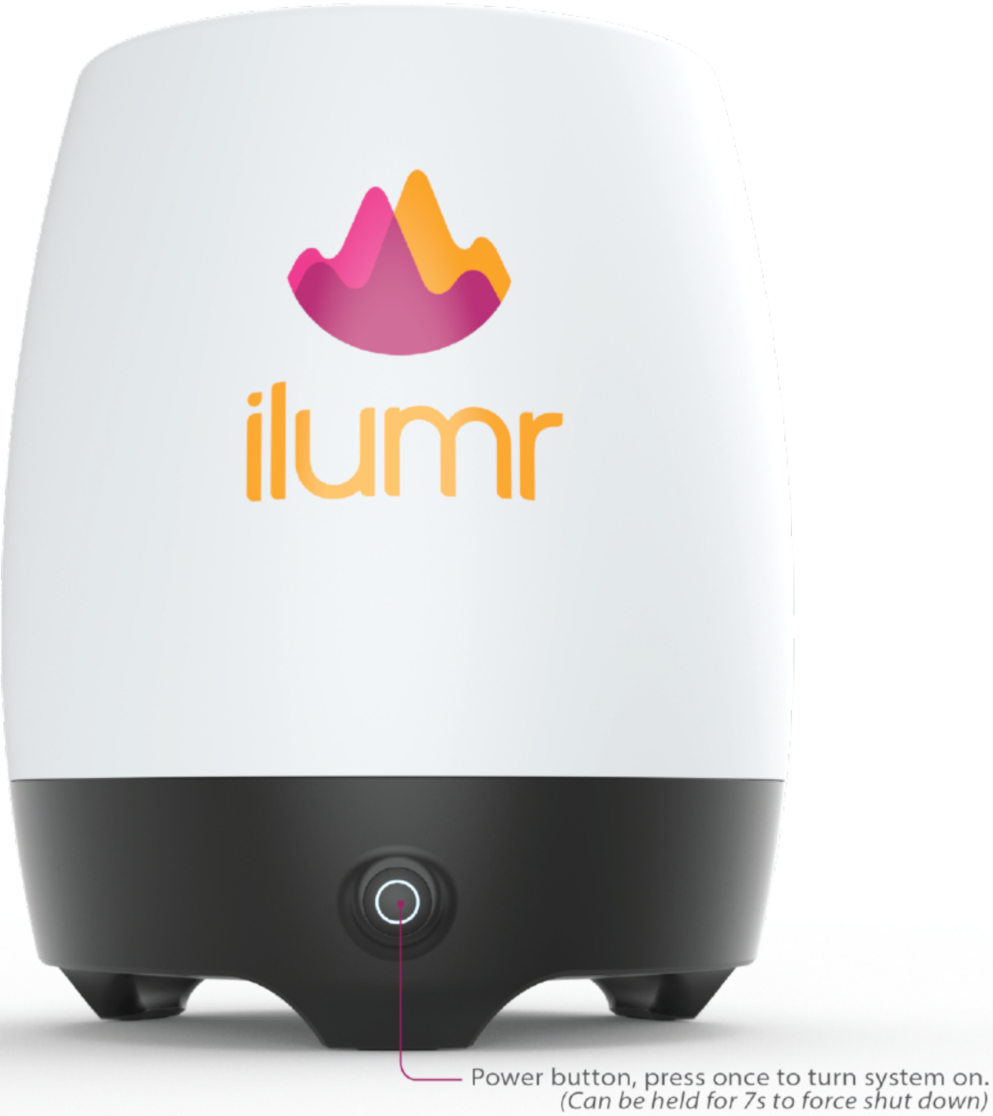
2. System Overview

As the ilumr is a sensitive NMR device it is important that the system is stable and correctly set up before use. This is a straightforward process and can be quickly achieved by following some basic steps, the ilumr software will automatically handle the lower level NMR related parameters in the background.

Remove the ilumr from its packaging and place on a stable desktop, please ensure all the protection wraps are removed before powering it on.

Read through the following to familiarise yourself with the system before following the setup steps.

2.1 Instrument front view

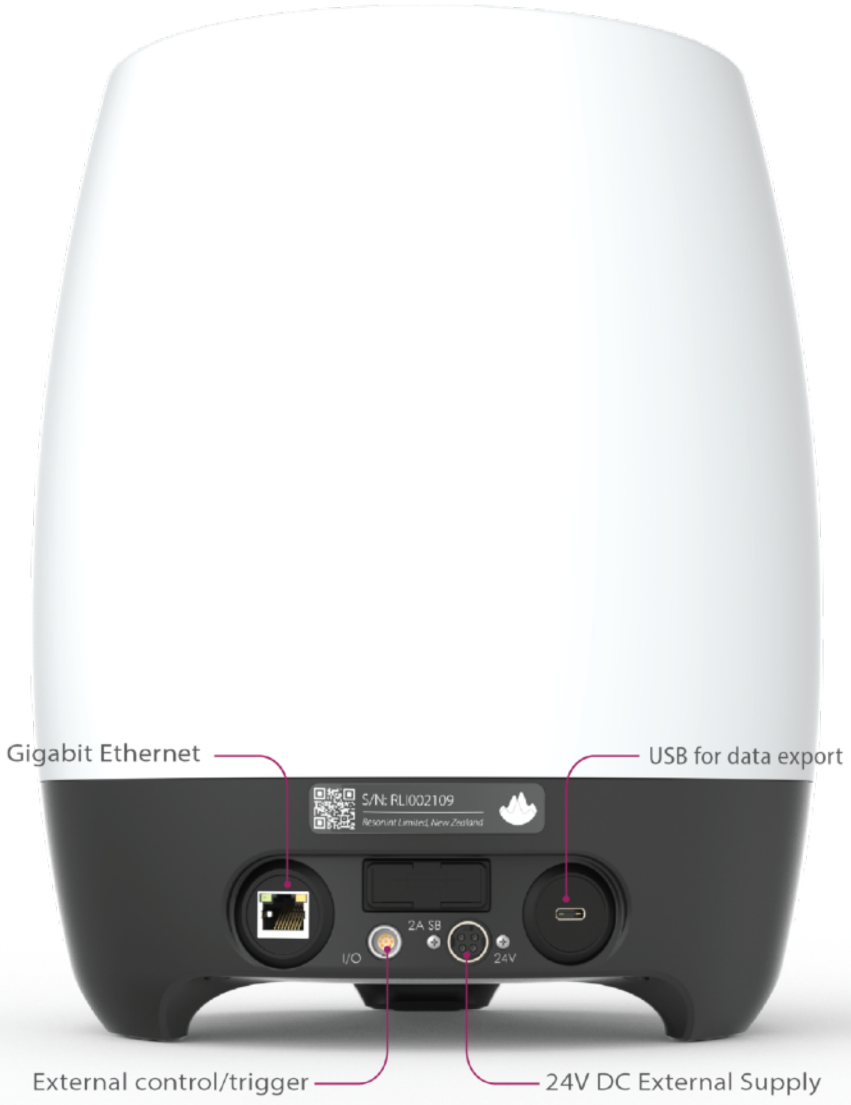

ilumr
Power button, press once to turn system on.
(Can be held for 7s to force shut down)

2.2 Instrument back view

To power the system on, connect the 24V DC power supply that shipped with ilumr and press the front power button once. ilumr will create its own WiFi access point which can be connected to for system control, it can also be plugged into your PC or local network using the Ethernet port.

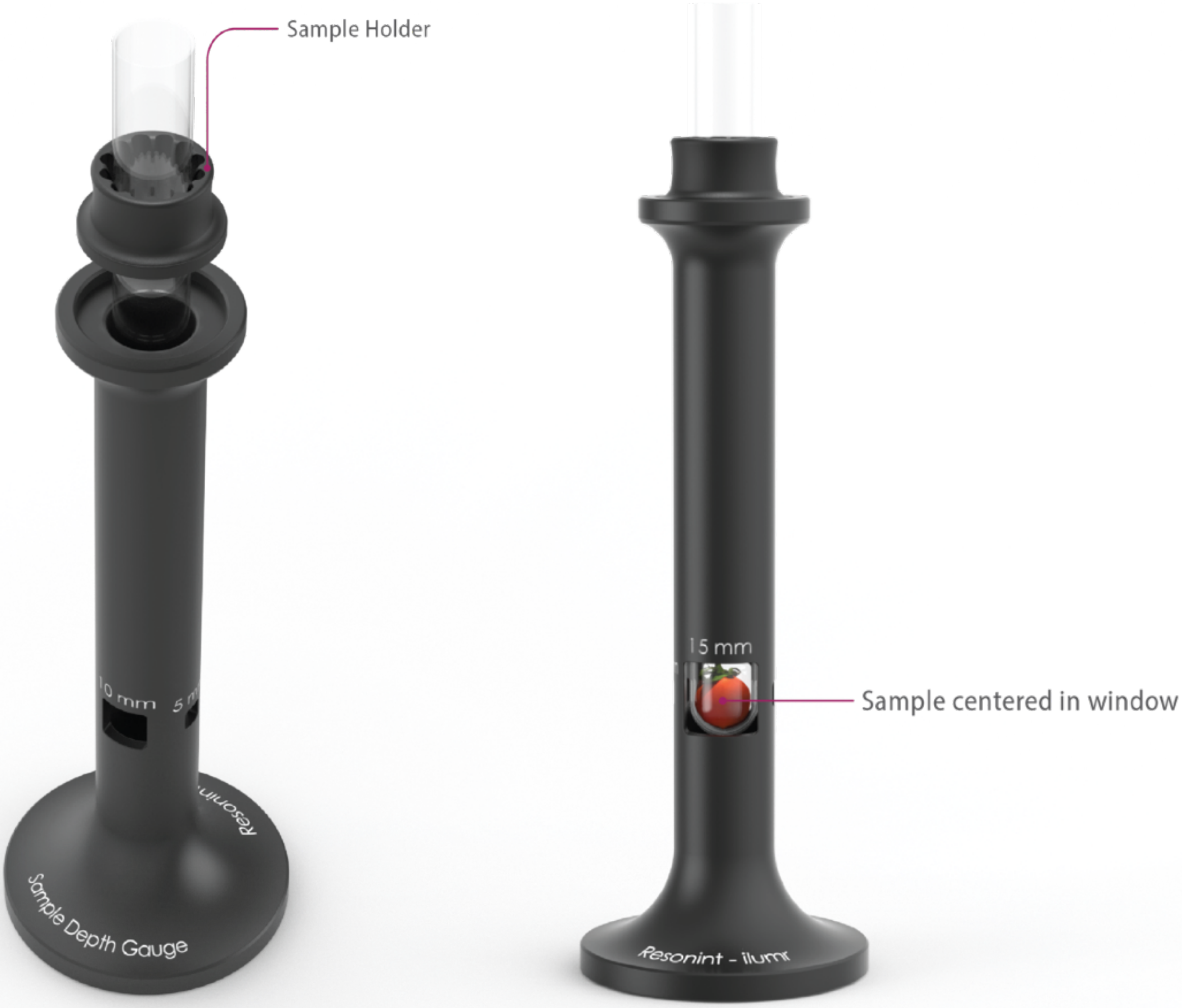
Future Update: The USB hub is for an external memory stick to act as an alternate location for saving files, please note this feature is not yet available. Please contact the Resonint team for more information.

ilumr also has the capability to control other devices through its I/O interface. Please contact the Resonint team for a guide on how to set up and use this feature.



2.3 Sample Depth Gauge

This simple gauge allows for easy positioning to ensure the sample or portion of the sample you would like to image is centered within the system's field of view. Place your chosen sample in one of the supplied glass tubes, fit a sample holder and then adjust the sample holder position using the depth gauge window.



To prepare the system for setting up and calibration, place the supplied shim sample according to the RF probe size fitted in ilumr. Ensure the entire sample is contained within the depth gauge window.

2.4 Connecting to ilumr

No software installation is required to use ilumr, the system is controlled through a web browser hosted on an internal computer running a linux operating system. Real-time communication trough a web socket allows for running experiments, processing data, and transferring it to the client PC.

Future Update: Currently all data processing is done on ilumr, work is being done on a locally installable environment that will communicate with ilumr using an API. This will allow for more powerful data processing using the local PC's resources. For more information please contact the Resonint team.

Connecting to ilumr is simple and can be done in any of the following 3 ways:

1. Using the ilumr WiFi network This is the most straightforward and convenient way of connecting to ilumr.

   Once ilumr has powered up it will generate its own WiFi access point based on the system serial number. For example, the serial number RLI01022018 would generate the following:

WiFi name:	ilumr-RLI01022018
WiFi password:	RLI01022018

   Note that using this method your PC will lose its internet connection if it gets internet via WiFi. This is not a problem if your PC gets an internet connection through ethernet.

2. Ethernet connection to your local router This can give the ilumr internet access for software updates as well as provide a simple way for multiple people to use the instrument.

   Using a standard ethernet cable, connect ilumr to your local router. In this case the IP address used to access the instrument will be assigned by the router. To find it, log into the routers admin page and check the connected devices list for "ilumr".

3. Ethernet connection to your PC If a connection to your local router is not possible then using an ethernet cable to connect to your PC will allow you to maintain an internet connection over WiFi while connected to ilumr. This setup requires some network configuration on the host PC: the easiest method is to enable internet sharing to the ethernet interface. See section 5.1 for details.

   Please also note that data transfer speeds over WiFi will be slower then when plugged in using ethernet

2.5 Loading the User Interface

The graphical interface for ilumr is built on JupyterLab, a web-based environment through which the system can be controlled. Powerful tools include a combination of high level GUI dashboards for common tasks and system setup as well a Python based notebook environment where workflows of data acquisition and processing can be created.

For more information on JupyterLab, visit www.jupyter.org

Once a WiFi connection with ilumr has been established, the JupyterLab interface can be loaded in a browser window at http://ilumr/ or using using the IP address directly:

http://192.168.0.4	*(for direct WiFi connection)*
http://<router assigned IP>	*(for router ethernet connection)*
http://192.168.137.2	*(for PC ethernet connection, section 5.1)*

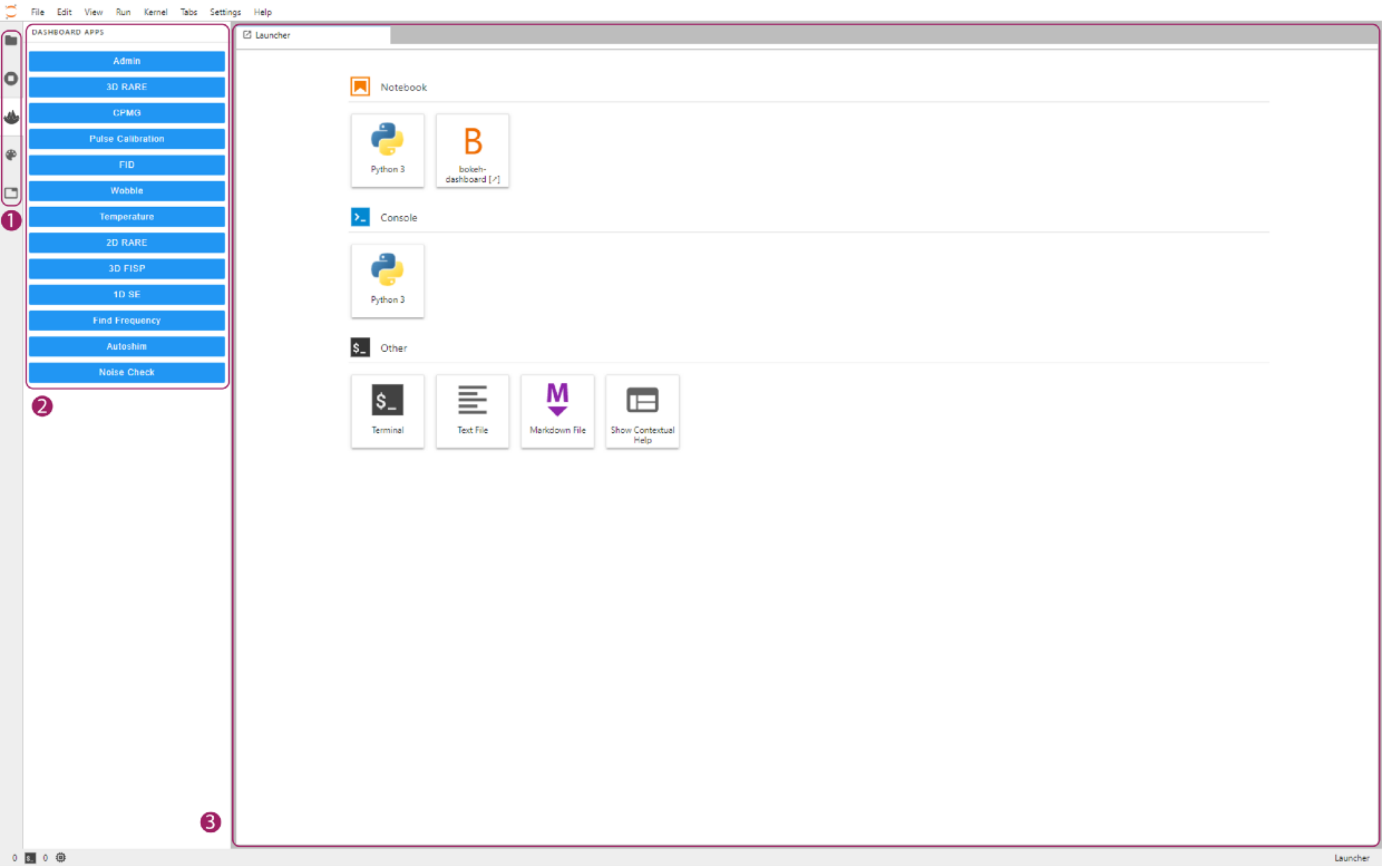
Note: For router ethernet connection, check router admin console for the list of connected devices and find the MAC address given in the test report.

An initialisation screen will be displayed as JupyterLab starts up and the environment will be automatically loaded when ready.

Continue with section 3.0 on the next page for an overview and guide on the Jupyter environment.

3. Setting Up & Dashboard Apps

Once logged in and loaded, the following will be displayed. Please note that loading on first start up can take a minute as JupyterLab initialises. Read through the following sections to familiarise yourself with the interface before setting up ilumr.



3.1 Jupyterlab interface components

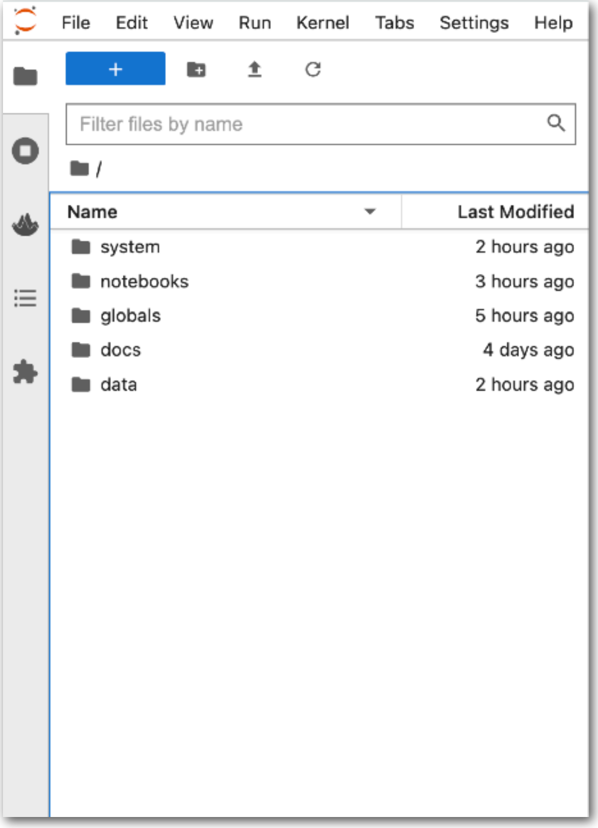
The 3 numbered areas in the above image highlight the menu and content elements most used in the Jupyterlab environment. The left sidebar (1. & 2.) contains a number of tabs (1.) that open sidebars (2.) that provide access to various features. The sidebar can be collapsed or expanded by simply clicking on the active tab.

The main work area (3.) is a customisable space where all active windows are displayed. Dashboards, terminals, notebooks, and text editors can be laid out in this space.

Carry on with the next page for examples of these interface elements.

Left Sidebar

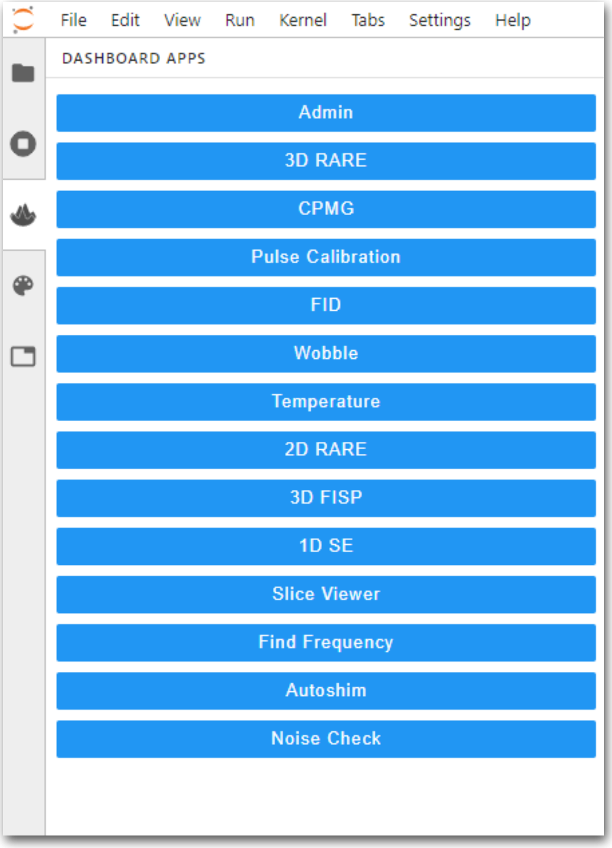
There are 5 tabs in the left sidebar which can be used to access the ilumr content and experiments. These are: first, a file browser; second, a list of running kernels and terminals, third, the ilumr dashboards; fourth, the command palette; and fifth, a list of tabs currently open in the main work area. Section 3.0 will cover the file browser and ilumr dashboard apps, please refer to the jupyterlab documentation (jupyterlab.readthedocs.io/en/1.2.x/) for more details on standard jupyterlab functions. Note that the dashboard app sidebar (with the ilumr icon) is an extension unique to ilumr, and not a part of the standard jupyterlab environment.



Name	Last Modified
system	2 hours ago
notebooks	3 hours ago
globals	5 hours ago
docs	4 days ago
data	2 hours ago

The file browser is a folder structure containing directories for system parameter files, custom jupyter notebooks, data saving, and user guides.

- system - Read-only folder containing Python code for system dashboard apps and pulse programs.
- notebooks - Directory for storing notebooks, these are powerful customisable workflows capable of data acquisition, processing, and visualisation. Some example notebooks are provided.
- globals - Files containing system related global parameters.
- data - Directory for data files saved by dashboard apps and notebooks



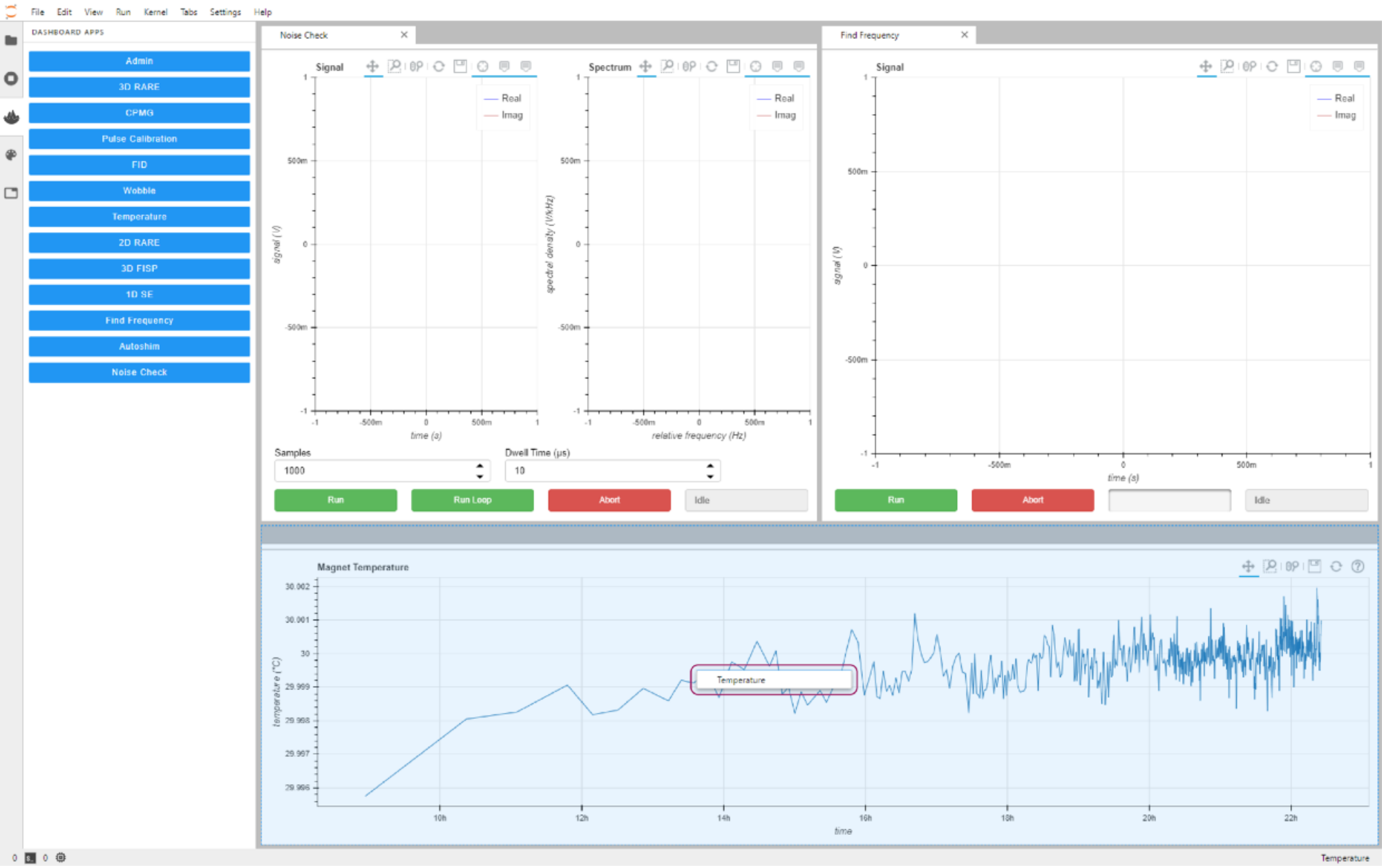
Clicking the ilumr icon will open up the dashboard apps menu. These provide the user with a simple way of both setting up the instrument for use and then running some standard experiments. The 3 main categories for these apps are as follows:

1. System setup
   - Admin
   - Noise Check
   - Temperature
   - Find Frequency
   - Wobble
   - Pulse Calibration
2. NMR dashboards
   - FID
   - CPMG
3. MRI dashboards
   - 1D SE
   - 2D RARE
   - 3D RARE
   - 3D FISP
   - Slice Viewer

Note: This may not be the complete list of available dashboards as new functionality is periodically released. Please contact Resonint for support with new dashboards.

Main work area

This area enables you to arrange dashboards and other activities into panels of tabs that can be resized or subdivided. To try, click a few of the dashboards to open them up. When clicked they will by default open on the currently active panel.



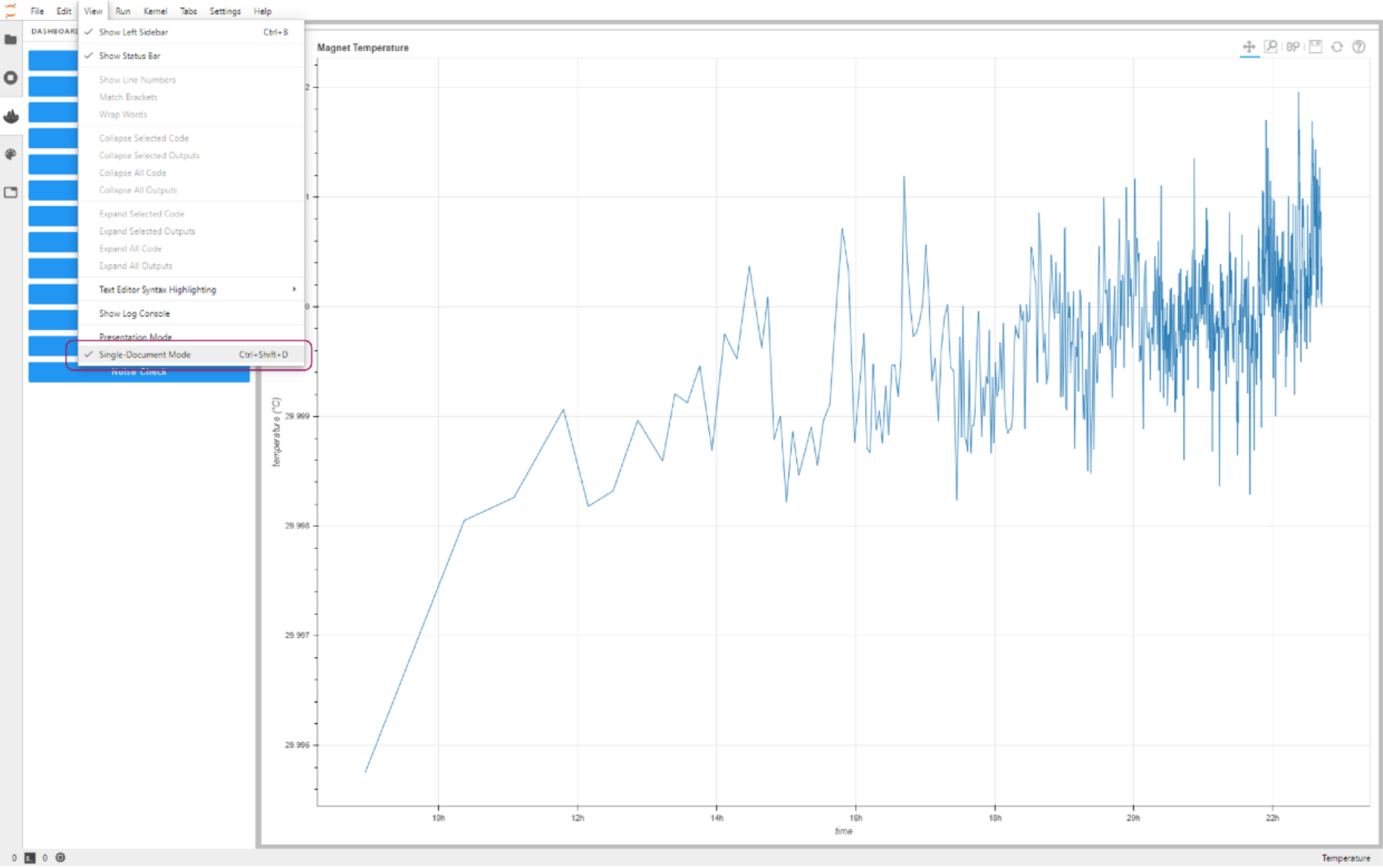
Try dragging a tab around the work area and see how options for subdividing the work area are highlighted in blue. Release the tab into an area and then resize it as required.

The work area can have a single interactive activity and this is marked with a colored blue top border on the tab. However dashboards that do not require interaction will continue to receive data even if not the current activity, for example the temperate monitoring dashboard.

Single-Document Mode

If you wish to expand the area a single activity is taking up in the work space without resizing or closing tabs to free up space there is an option called Single-Document Mode. You can access this using the View menu, when toggled the current active tab will fill the entire work area. When leaving Single-Document Mode, the original layout of the main area is restored.

This feature is particularly useful when controlling the instrument using an iPad or touch screen device. Simply switch to simple interface mode and then leaving the Dashboard Apps menu open, toggle between required apps.



Continue with Section 3.2 to setup and run experiments on ilumr using dashboards.

3.2 Dashboard Apps

The ilumr system comes with a number of preinstalled apps for setting up and running experiments, these can be found in the navigation tab with the ilumr logo as previously discussed.

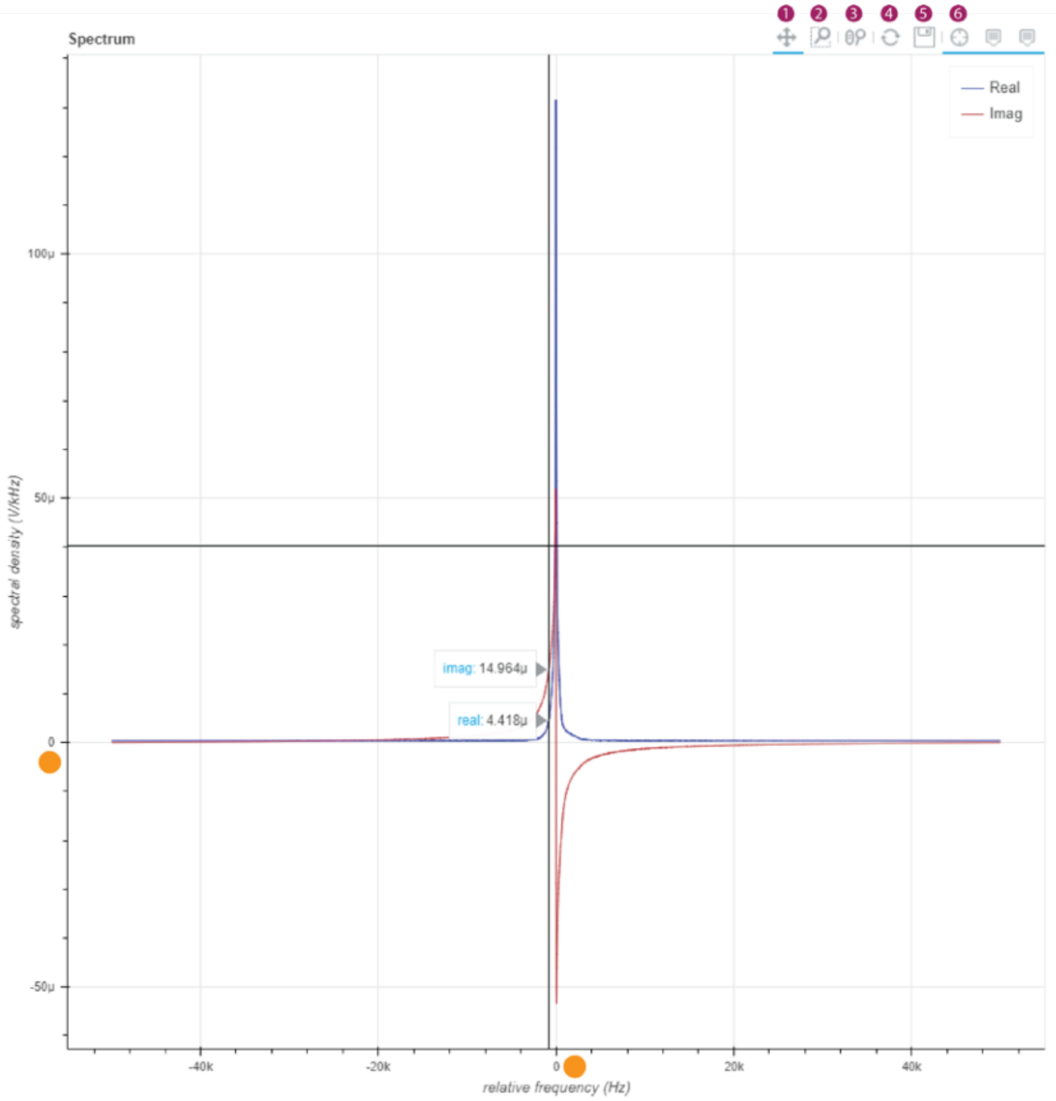
Read through and follow the guides for each dashboard in the order presented to set up and use ilumr. In preparation, the provided 10mm Shim Sample can be depth gauged and placed in the system.

3.2.1 Dashboard tools & features

There are a number of tools and features common to all dashboards.

Plotting Tools

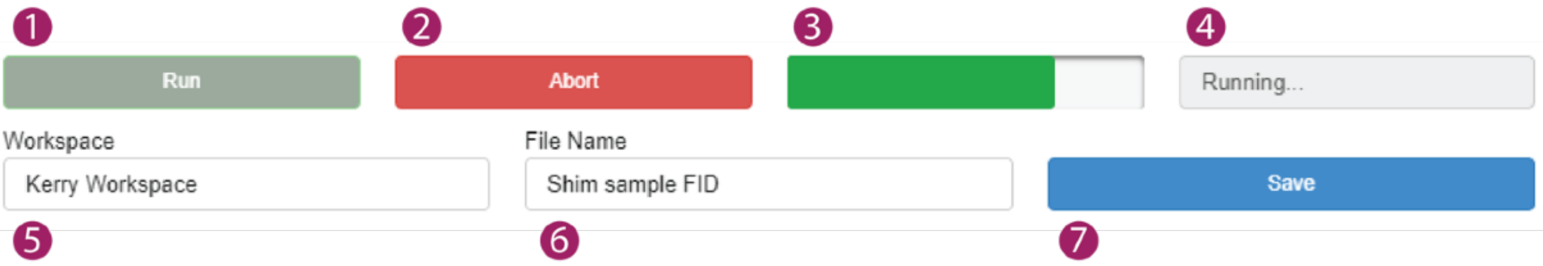
The plots generated within dashboards are interactive bokeh plots and have the following features which can be toggled by clicking their icons.



1. Left click and drag to pan
2. Select area to zoom
3. Zoom with mouse wheel, position within plot to zoom both axes or over an individual axis (orange points) to zoom only on that axis
4. Reset the plot
5. Save a PNG (follows browser settings for downloads)
6. Toggle crosshairs

Running Experiments & Data Saving

Each dashboard has a control bar with the following features.



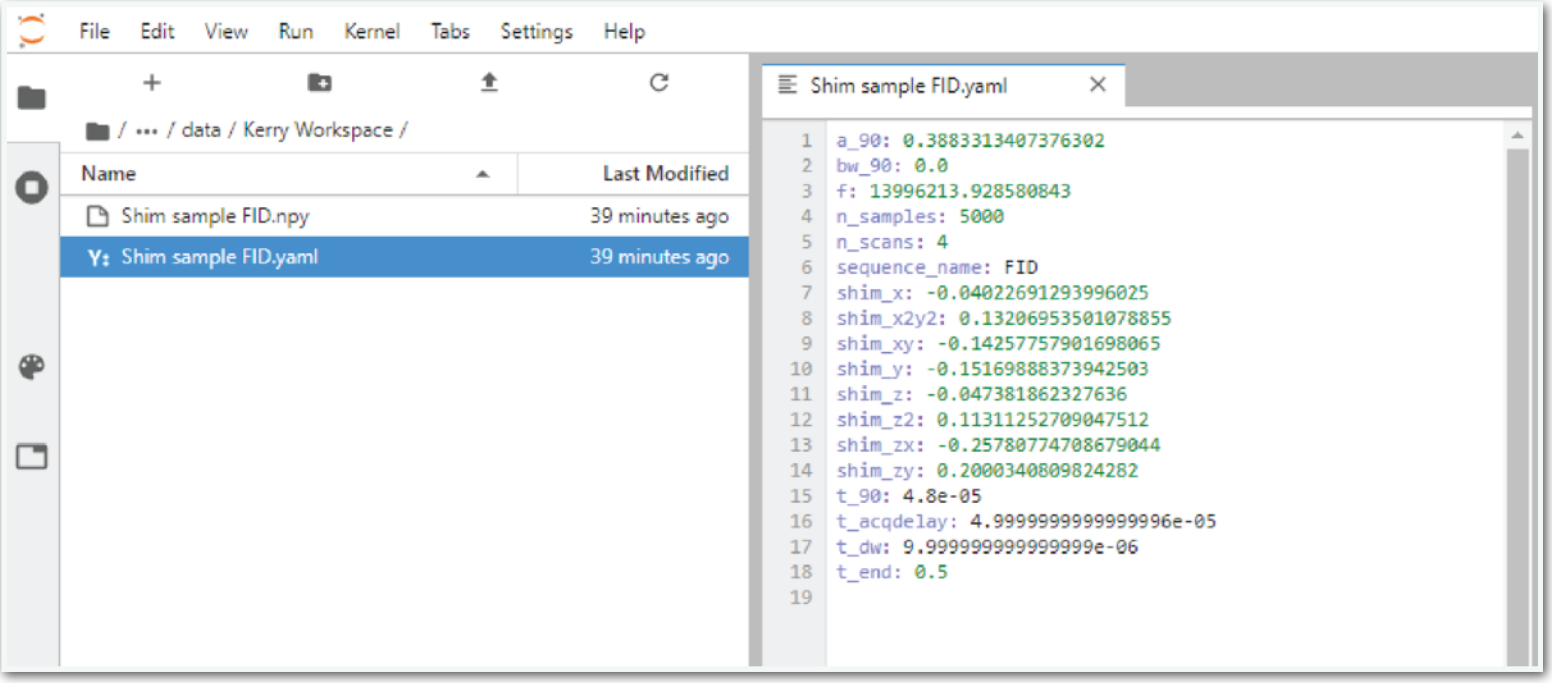
Workspace: Kerry Workspace

File Name: Shim sample FID

1. Run the experiment - will grey out while an experiment is running and disable the running of other dashboards.
2. Abort the experiment
3. Progress bar
4. Status bar - will display current status and error messages.
5. Saving directory - will save the data to "user/data/<Workspace>/<File Name>". Subdirectories can also be specified using a "/", e.g. "kerry/3D" to save to "user/data/kerry/3D/<File Name>".
6. File name - will save with this file name within the chosen workspace directory, as in the image below.
7. Save - save the data (data will not be autosaved).

When saving, a second file containing the pulse sequence parameters used in the experiment will also be saved alongside as a .yaml file.

Autosaved Parameters

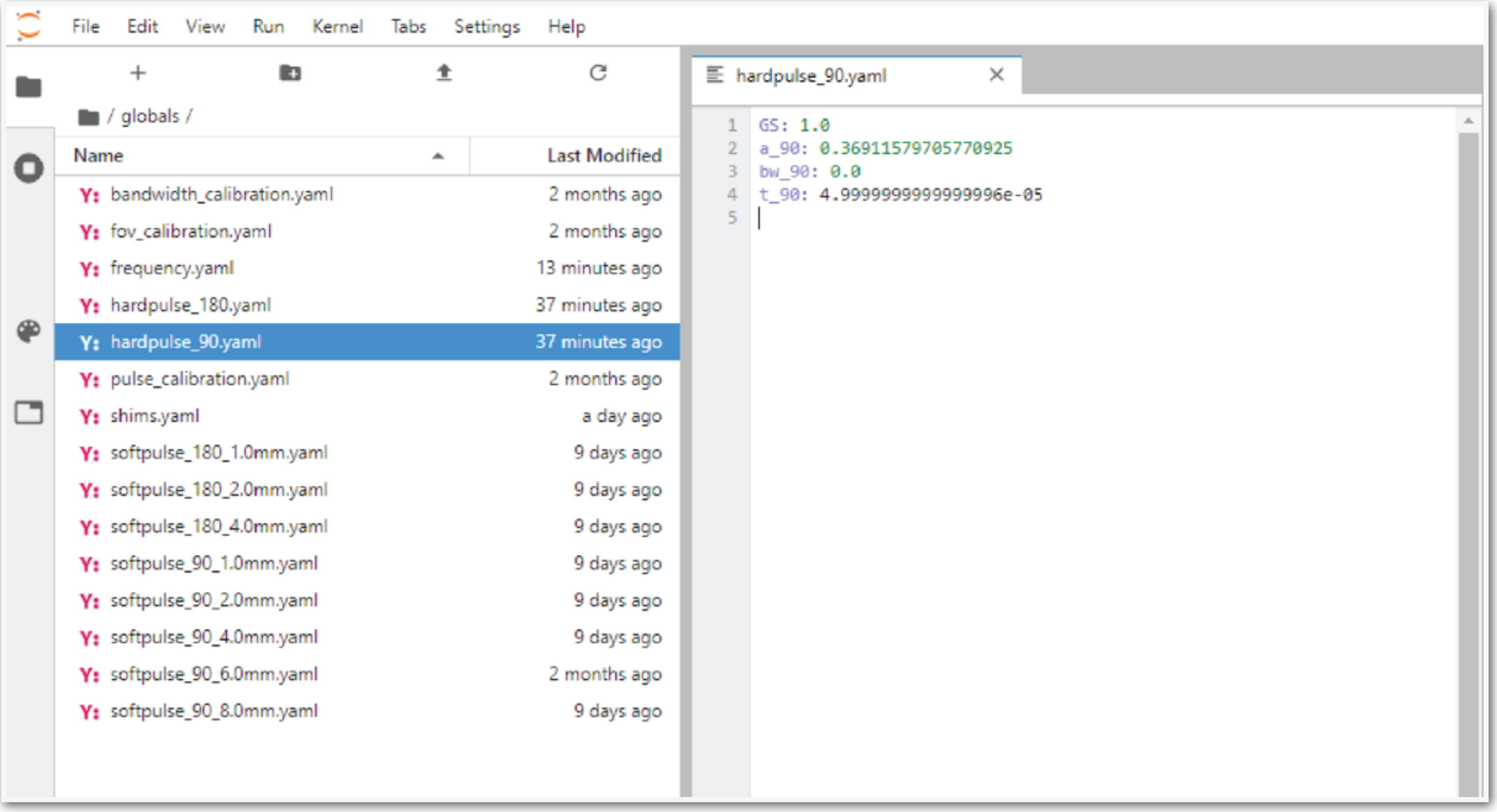


/ ••• / data / Kerry Workspace /

Name	Last Modified
Shim sample FID.npy	39 minutes ago
Shim sample FID.yaml	39 minutes ago

```
a_90: 0.3883313407376302
bw_90: 0.0
f: 13996213.928580843
n_samples: 5000
n_scans: 4
sequence_name: FID
shim_x: -0.04022691293996025
shim_x2y2: 0.13206953501078855
shim_xy: -0.14257757901698065
shim_y: -0.15169888373942503
shim_z: -0.047381862327636
shim_z2: 0.11311252709047512
shim_zx: -0.25780774708679044
shim_zy: 0.2000340809824282
t_90: 4.8e-05
t_acqdelay: 4.9999999999999996e-05
t_dw: 9.999999999999999e-06
t_end: 0.5

```

The dashboard apps used for configuring and setting up the instrument will automatically update system parameters when run. These system parameter sets can be found in files in the "globals" directory as shown in the image below. These files are not intended to be changed manually under normal circumstances.



Name	Last Modified
bandwidth_calibration.yaml	2 months ago
fov_calibration.yaml	2 months ago
frequency.yaml	13 minutes ago
hardpulse_180.yaml	37 minutes ago
hardpulse_90.yaml	37 minutes ago
pulse_calibration.yaml	2 months ago
shims.yaml	a day ago
softpulse_180_1.0mm.yaml	9 days ago
softpulse_180_2.0mm.yaml	9 days ago
softpulse_180_4.0mm.yaml	9 days ago
softpulse_90_1.0mm.yaml	9 days ago
softpulse_90_2.0mm.yaml	9 days ago
softpulse_90_4.0mm.yaml	9 days ago
softpulse_90_6.0mm.yaml	2 months ago
softpulse_90_8.0mm.yaml	9 days ago

```yaml
GS: 1.0
a_90: 0.36911579705770925
bw_90: 0.0
t_90: 4.9999999999999996e-05

```

3.2.2 Admin

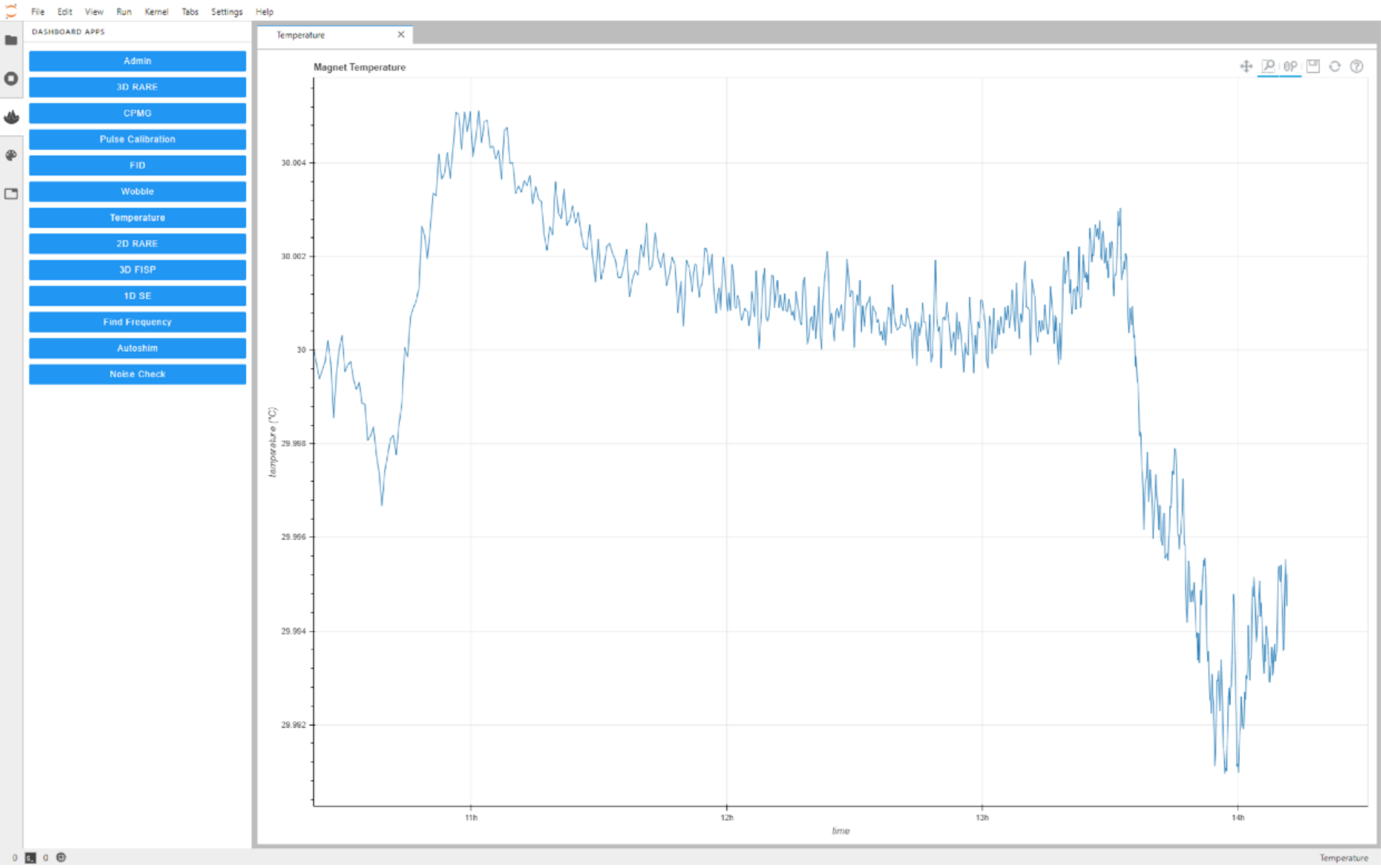
From this dashboard the system can be shutdown, please use the shutdown button here to turn the system off and not the front button on the ilumr to avoid loss of data.

The Admin Dashboard can also be used to download and install any new firmware or software updates, the Resonint team will inform you when updates are available. Please ensure the system has an internet connection by plugging it into a router before clicking the Update button. This will usually take approximately 15 minutes and the system must not be turned off during this process. When completed, ilumr will restart the hardware driver and jupyterlab at which point you can refresh the browser to reconnect and login.

3.2.3 Temperature

The magnet in ilumr is temperature controlled to keep the system frequency stable and uses a PT100 sensor to measure its temperature.

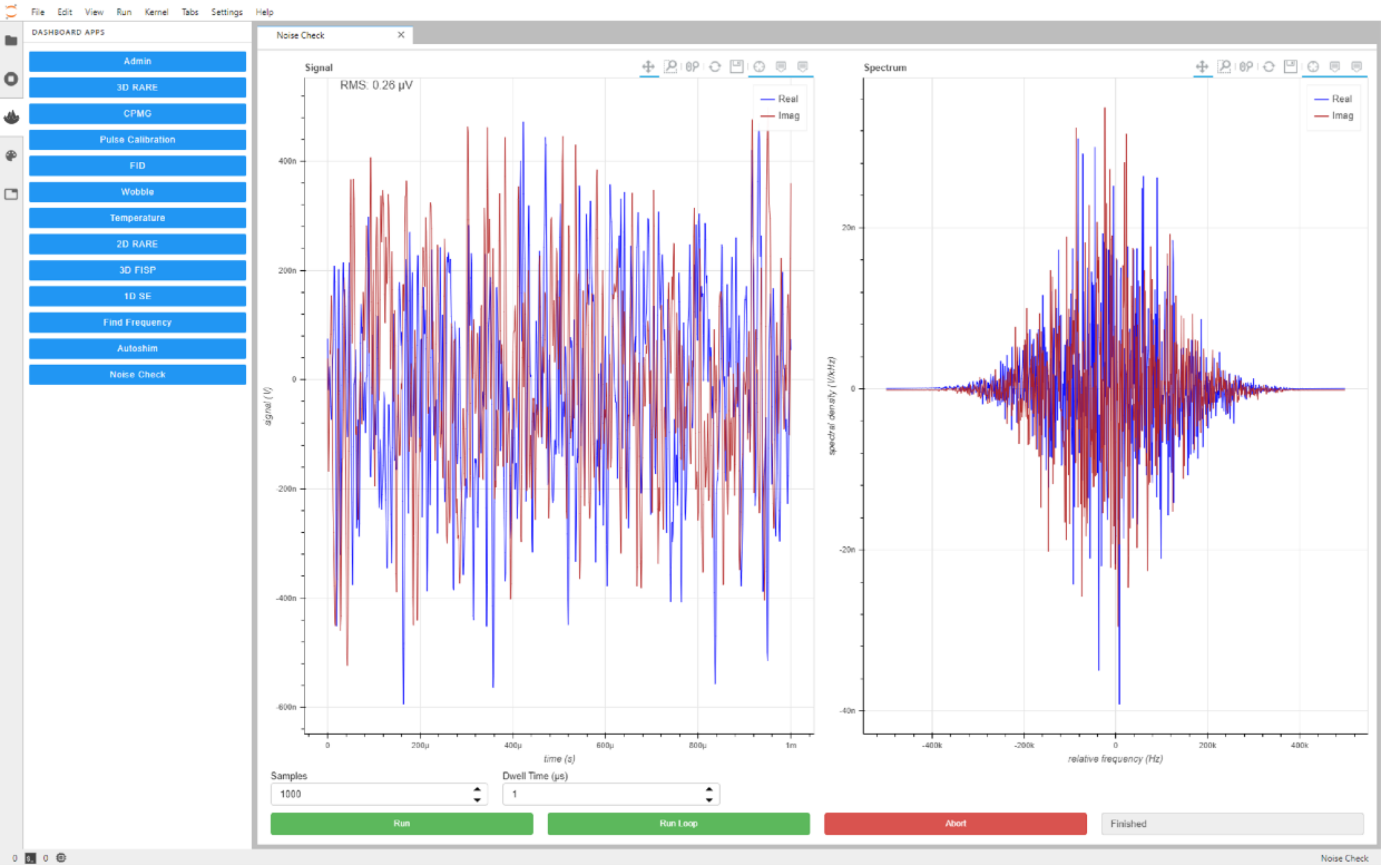
The set control point is 30°C, please ensure that the system has reached and held this temperature for at least 30 minutes before continuing with the setup process.



If you need to change the magnet temperature for reasons such as operating in an environment outside of the recommended 15°C - 25°C then please contact the Resonint support team.

3.2.4 Noise Check

Once the system temperature is stable you can perform a Noise Check. Click Run or Run Loop and the system will measure and display the noise level. Use this dashboard to make sure that the operating environment is suitable for ilumr with no large sources of electrical interference. Interference will show up as large spikes extending higher then the baseline noise level. The RMS of the noise signal is displayed in the top left, and should be less than 0.3 µV when using a dwell time of 1 µs. Note that the data shown here is raw data from the hardware decimator, which does not have a flat frequency response, so the noise spectrum (right-hand plot) will normally have a bell-curve-like shape as shown below:



RMS: 0.26 µV

Samples
1000

Dwell Time (µs)
1

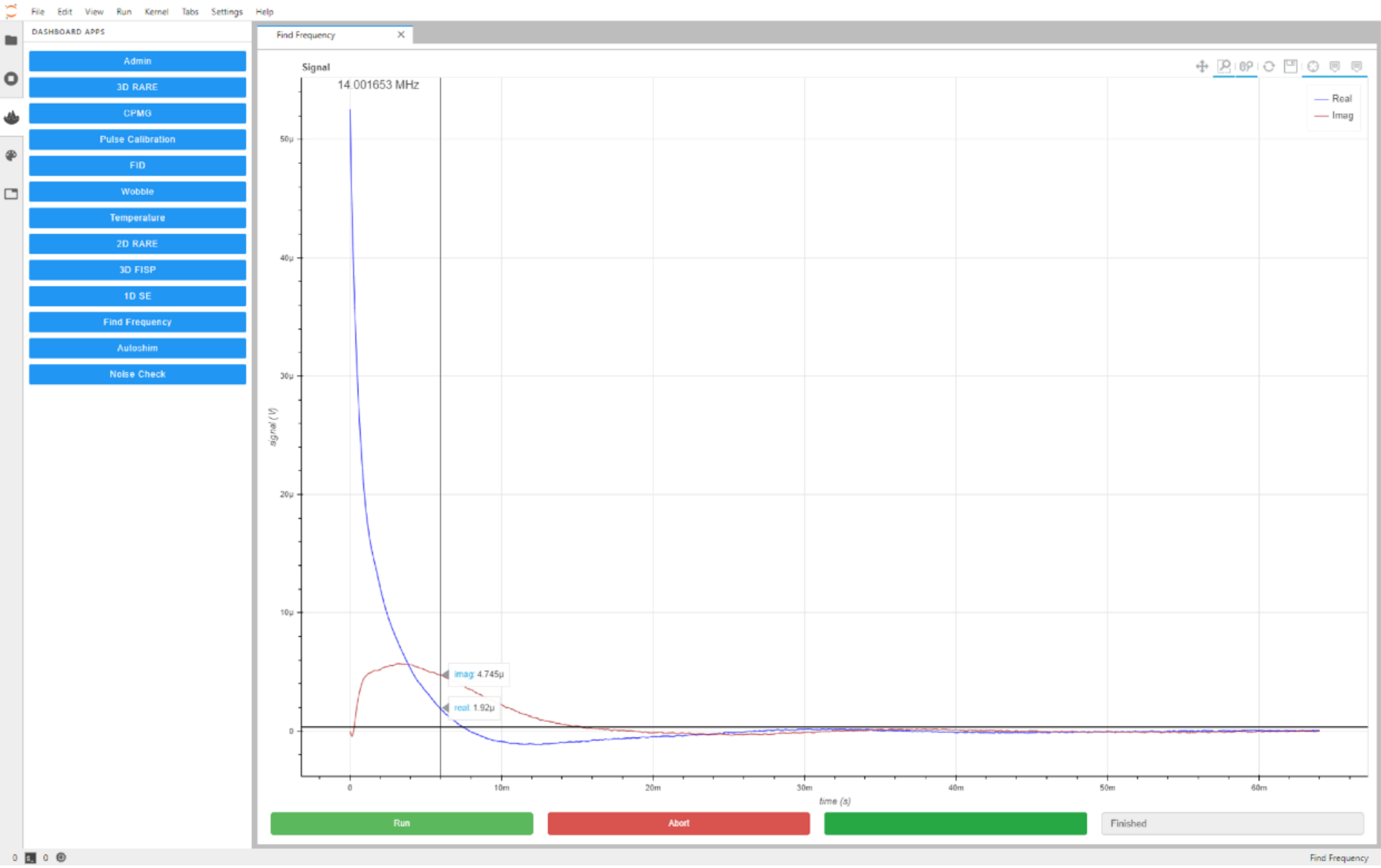
Finished

3.2.5 Find Frequency

The next dashboard to run is Find Frequency which uses an FID pulse sequence with several dwell time increments in order to determine the NMR frequency of the magnet.

Begin by depth gauging the supplied shim sample and insert into the system. Press Run to perform the experiment and determine the NMR frequency. The new frequency value is automatically saved and can be found in the following location:

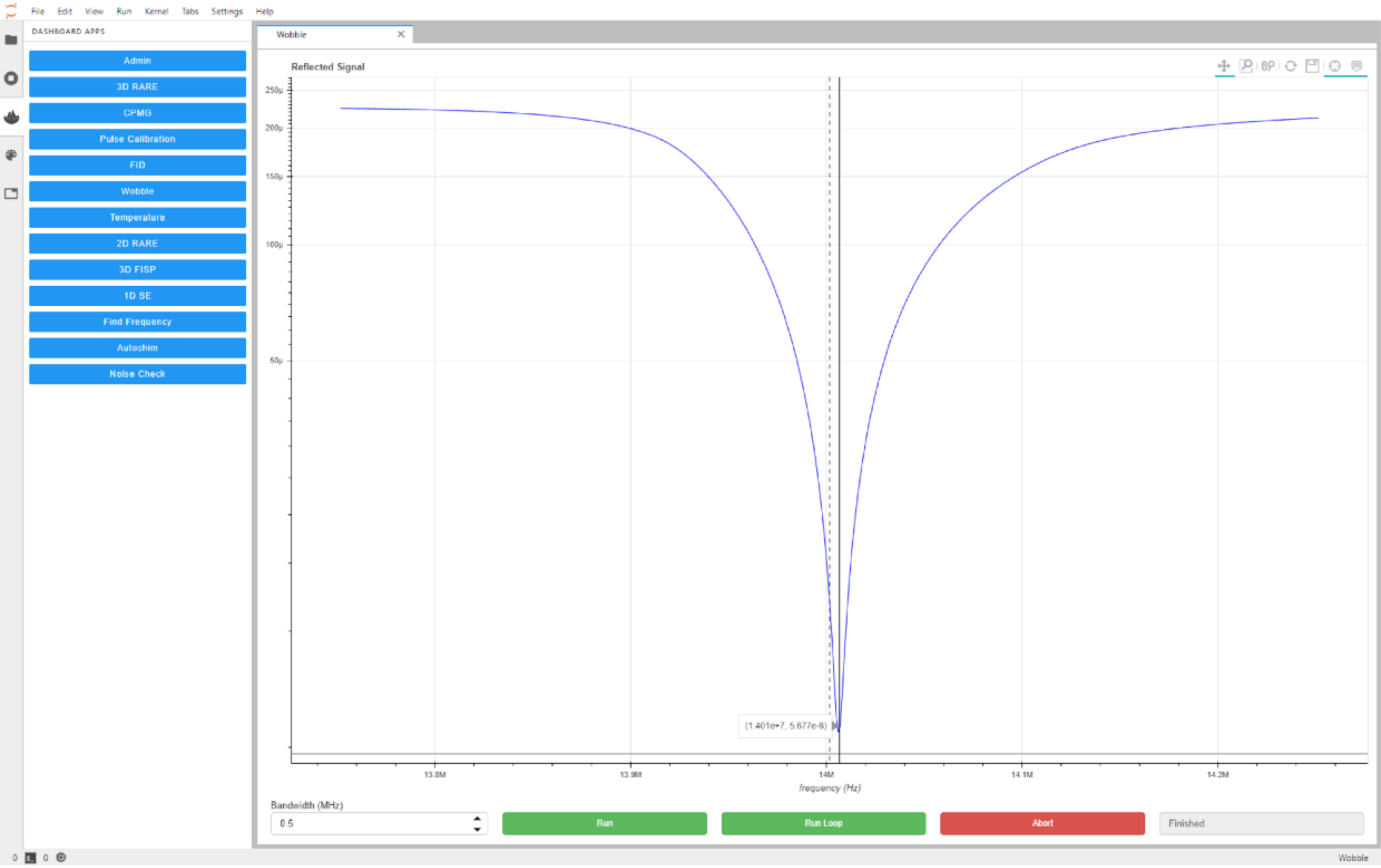
globals/frequency.yaml



3.2.6 Wobble

The RF probes supplied with ilumr have been tuned to the magnet's resonant frequency. However due to differences in operating environments this frequency may shift slightly. It is important to have the probe tuned to the magnet frequency, so before running NMR experiments perform a wobble to check and adjust the probe tuning if required.

In the graph below, the dotted line indicates the magnet frequency, taken from the frequency found in the previous dashboard. This is an example of a well tuned probe, small offsets from the NMR frequency are not a problem and may also be caused by a change in sample. Try removing the shim sample while running the wobble in looped mode to see the effect.



Bandwidth (MHz) 0.5

Finished

A well tuned probe should meet the following requirements:

Tune: NMR frequency +/- 0.02MHz

Match: less then 20 µV (20e-6) at NMR frequency

If the probe tunings falls outside of these requirements then please follow the next steps with the Wobble running on loop.

Remove the top disk by rotating anti-clockwise. Then using the supplied trimmer tool, adjust the tune & match capacitors until values fall within the recommended range.

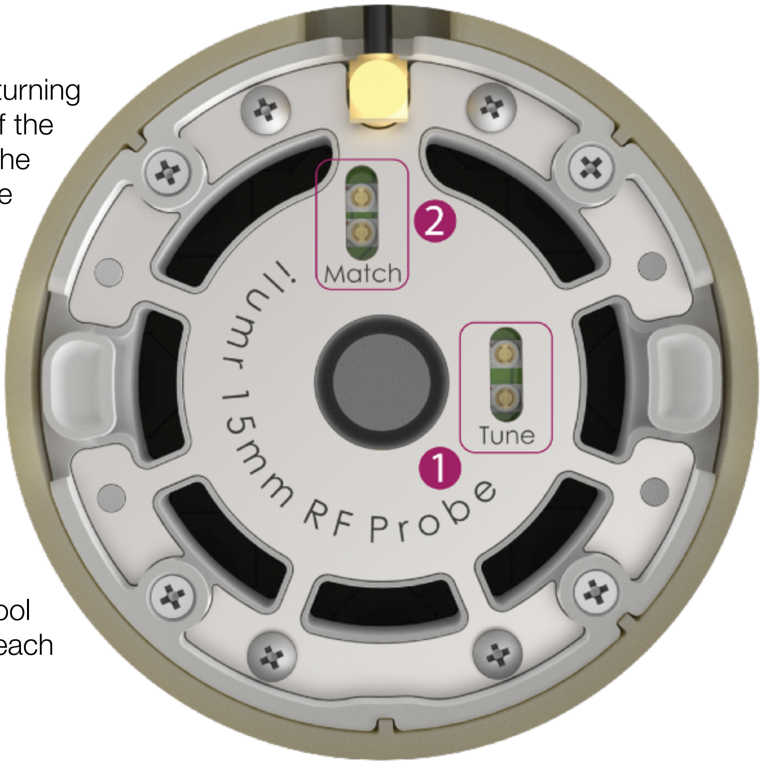
The bottom tune/match capacitor is for coarse adjustment and the top for fine adjustment.

ilumr - 15mm RF Probe

Each capacitor has a tiny arrow on the turning part and a notch on the rim. One end of the adjustment range is reached when the arrow is aligned with the notch, and the other end is reached when the arrow is pointing in the opposite direction.

The general tuning method is to first adjust the fine capacitors to 90° from the notch (the halfway point of its range), then adjust the coarse capacitors to get the tune/match roughly correct, then use the fine capacitors.

Note that the presence of the trimmer tool will shift the value so remove after each small adjustment to check.



3.2.7 Pulse Calibration

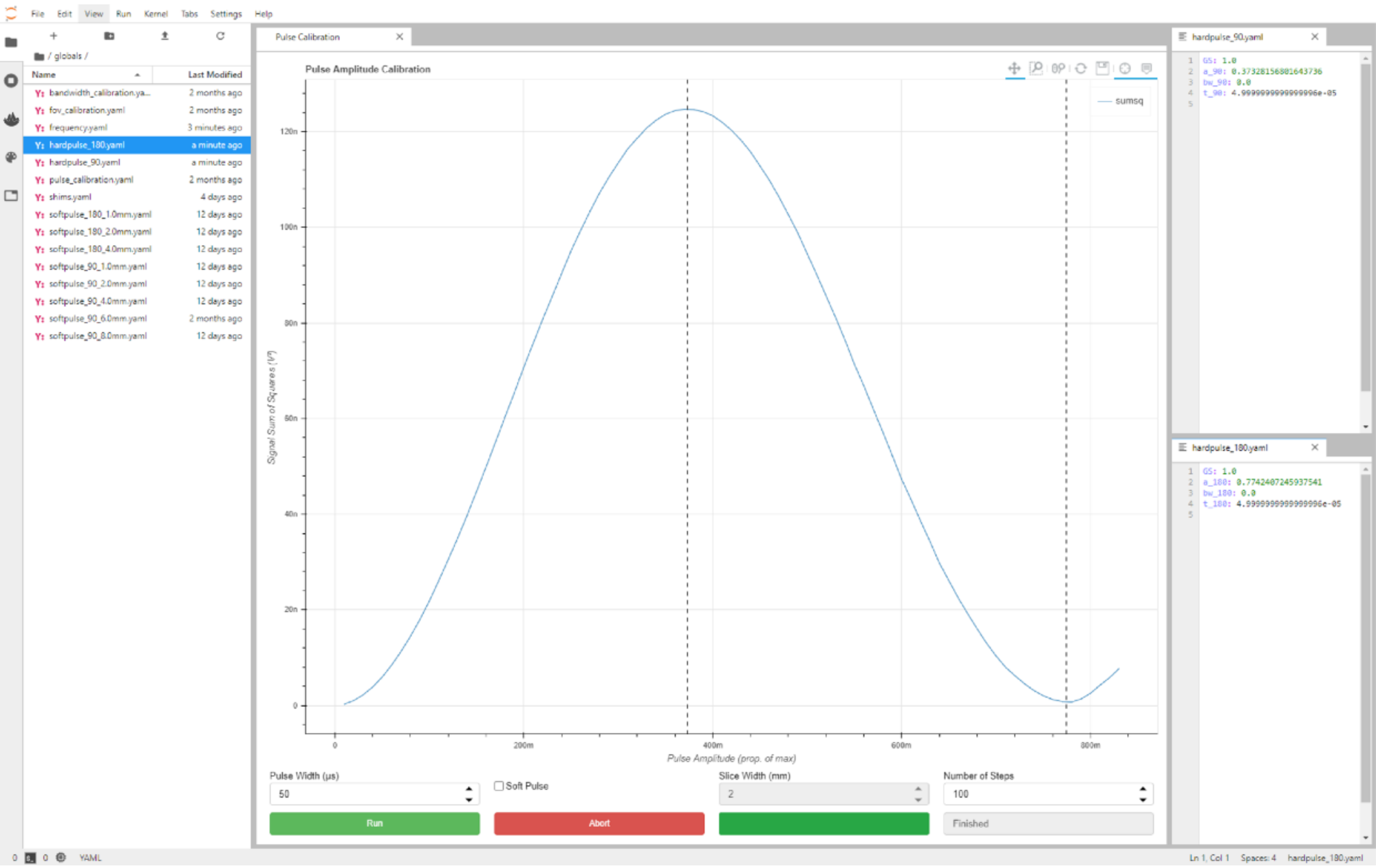
Once the tuning/matching of the probe has been confirmed, the pulse power of 90 and 180 degree RF pulses can be calibrated using this dashboard. The default settings should be adequate for the 10 mm probe, but the 15 mm probe will require a longer pulse width (recommended 60 us) to achieve a 180 degree tipping angle. Once complete, vertical dotted lines will show the amplitudes of the 90 and 180 degree pulses and the settings will be automatically save to the following files (when not calibrating a soft pulse):

globals/hardpulse_90.yaml
globals/hardpulse_180.yaml

To calibrate soft pulses for MRI slice experiments, check the *Soft Pulse* option and set the desired *Slice Width*. The pulse width will auto-populate with a value that should be suitable, and when finished the settings will be saved to files named:

globals/softpulse_90_<slice width>mm.yaml
globals/softpulse_180_<slice width>mm.yaml

If the 180 degree tipping angle is not reached, the corresponding file will not be created.



/ globals /

Name	Last Modified
bandwidth_calibration.ya...	2 months ago
fov_calibration.yaml	2 months ago
frequency.yaml	3 minutes ago
hardpulse_180.yaml	a minute ago
hardpulse_90.yaml	a minute ago
pulse_calibration.yaml	2 months ago
shims.yaml	4 days ago
softpulse_180_1.0mm.yaml	12 days ago
softpulse_180_2.0mm.yaml	12 days ago
softpulse_180_4.0mm.yaml	12 days ago
softpulse_90_1.0mm.yaml	12 days ago
softpulse_90_2.0mm.yaml	12 days ago
softpulse_90_4.0mm.yaml	12 days ago
softpulse_90_6.0mm.yaml	2 months ago
softpulse_90_8.0mm.yaml	12 days ago

Pulse Width (µs): 50
□ Soft Pulse
Slice Width (mm): 2
Number of Steps: 100
Finished

hardpulse_90.yaml

```
GS: 1.0
a_90: 0.37328156801643736
bw_90: 0.0
t_90: 4.999999999999996e-05
```

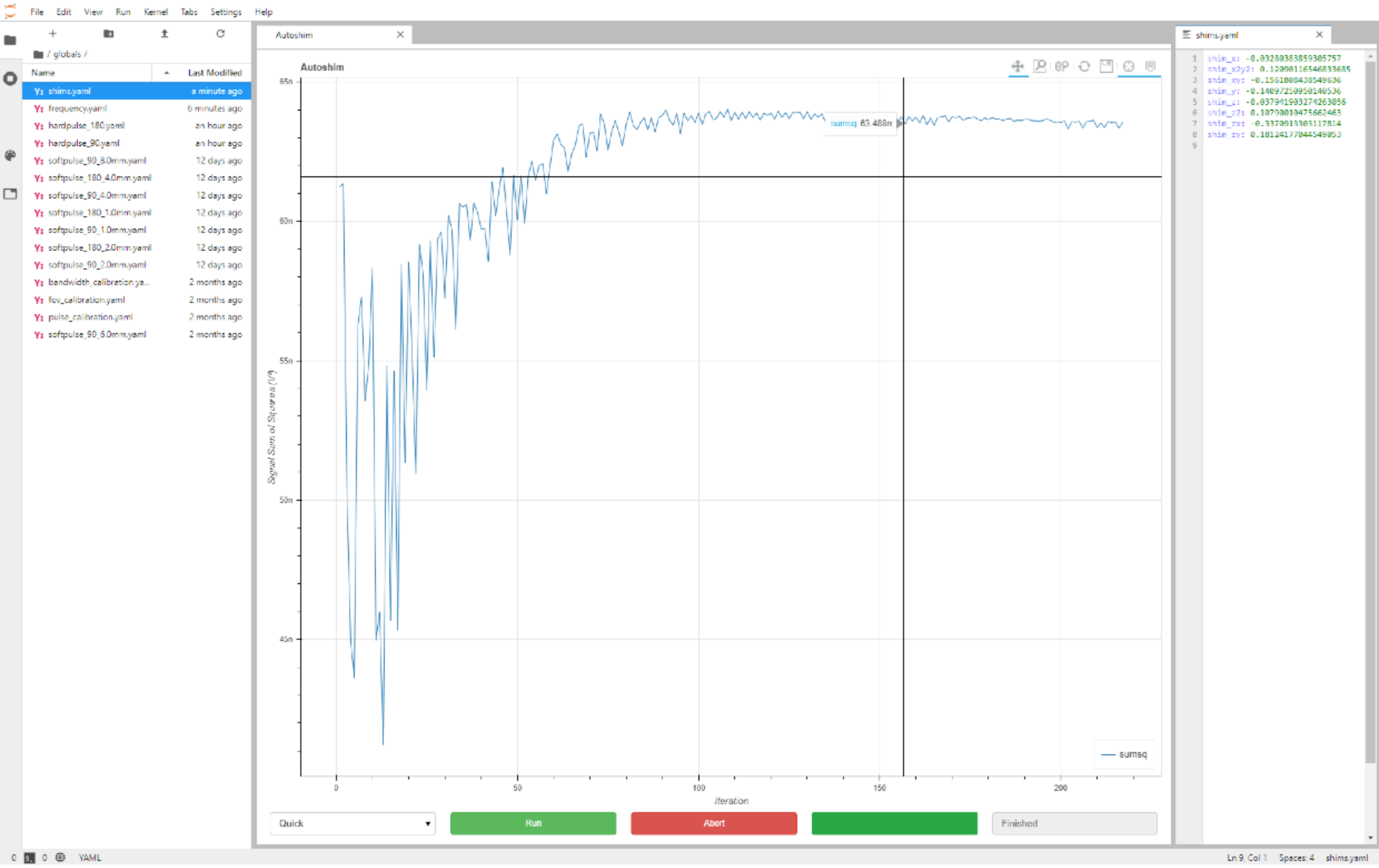
hardpulse_180.yaml

```
GS: 1.0
a_180: 0.7742407245937541
bw_180: 0.0
t_180: 4.999999999999996e-05
```

3.2.8 Autoshim

The final setup step is determining the electrical shim settings, which is done by *Autoshim*. The first time this is run after power up (and leaving for some time for the temperature to stabilise) the *Coarse* settings should be selected in the bottom left for it to start from scratch. A *Quick* shim can be run periodically to re-optimise the homogeneity if it has drifted (due to small changing thermal gradients in the magnet). The shim values are automatically saved to the shims file (with values in the range [-1, 1]):

globals/shims.yaml



Name	Last Modified
shims.yaml	a minute ago
frequency.yaml	6 minutes ago
hardpulse_180.yaml	an hour ago
hardpulse_90.yaml	an hour ago
softpulse_90_8.0mm.yaml	12 days ago
softpulse_180_4.0mm.yaml	12 days ago
softpulse_90_4.0mm.yaml	12 days ago
softpulse_180_1.0mm.yaml	12 days ago
softpulse_90_1.0mm.yaml	12 days ago
softpulse_180_2.0mm.yaml	12 days ago
softpulse_90_2.0mm.yaml	12 days ago
bandwidth_calibration.ya...	2 months ago
fov_calibration.yaml	2 months ago
pulse_calibration.yaml	2 months ago
softpulse_90_6.0mm.yaml	2 months ago

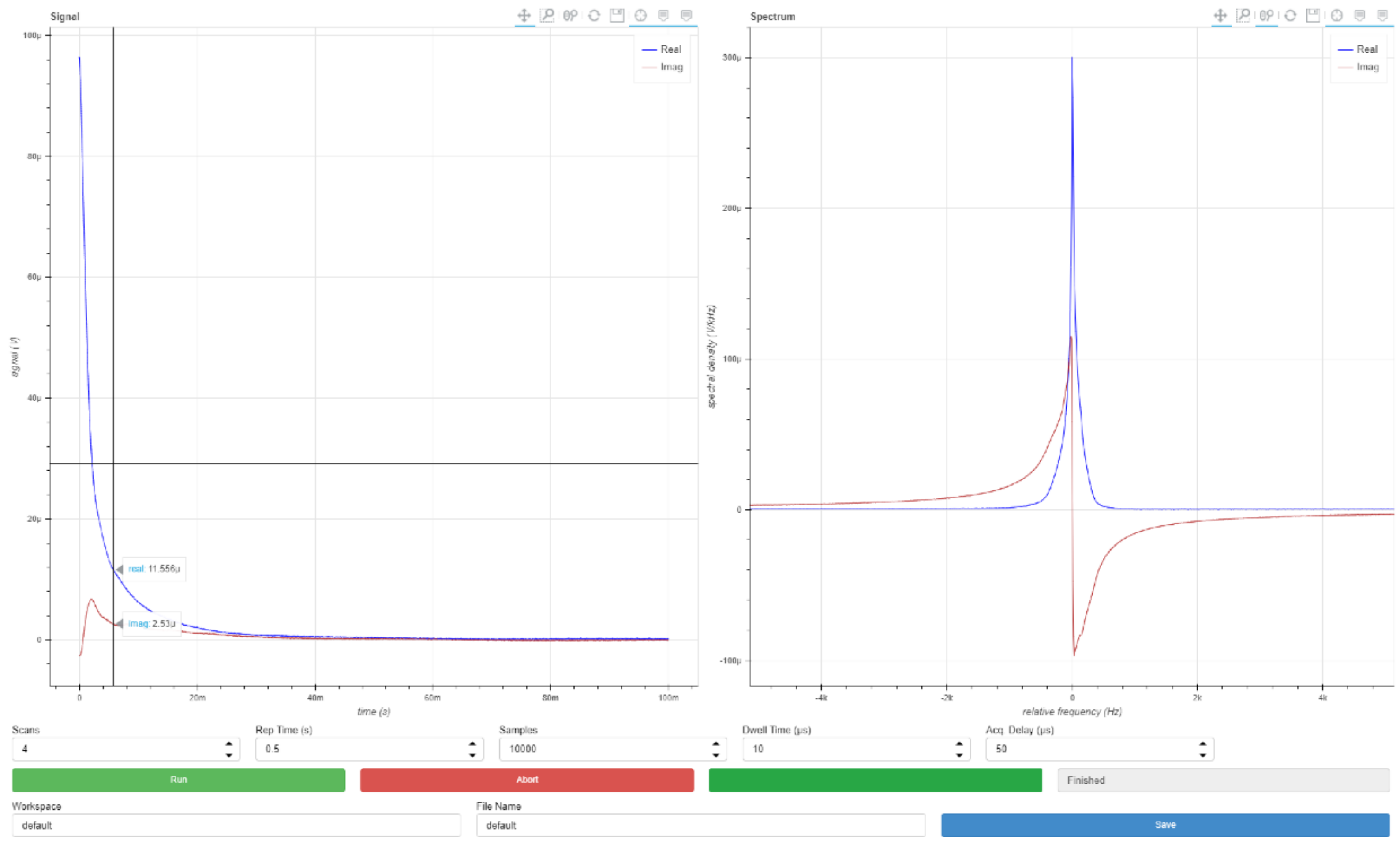
```
shim_x: -0.03280383859305757
shim_x2y2: 0.12090116546833685
shim_xy: -0.1561808438549636
shim_y: -0.1409725095014O536
shim_z: -0.03794190327426305б
shim_z2: 0.1079001047566246З
shim_zx: -0.3370913303117814
shim_zy: 0.1012417784454985З
```

3.2.9 FID

This experiment runs a Free Induction Decay pulse sequence with the following parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans.
- Rep Time - time waited between scans, may need to be increased for samples with a long T1 recovery time (e.g. pure water).
- Samples- number of complex samples acquired.
- Dwell Time - time between sample, longer dwell time will result in a narrower bandwidth in the *Spectrum* plot on the right.
- Acq. Delay - time delay after the RF pulse to allow for probe/duplexer dead time, should not need to be modified.

Note: frequency, pulse power/width, and shim settings are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.



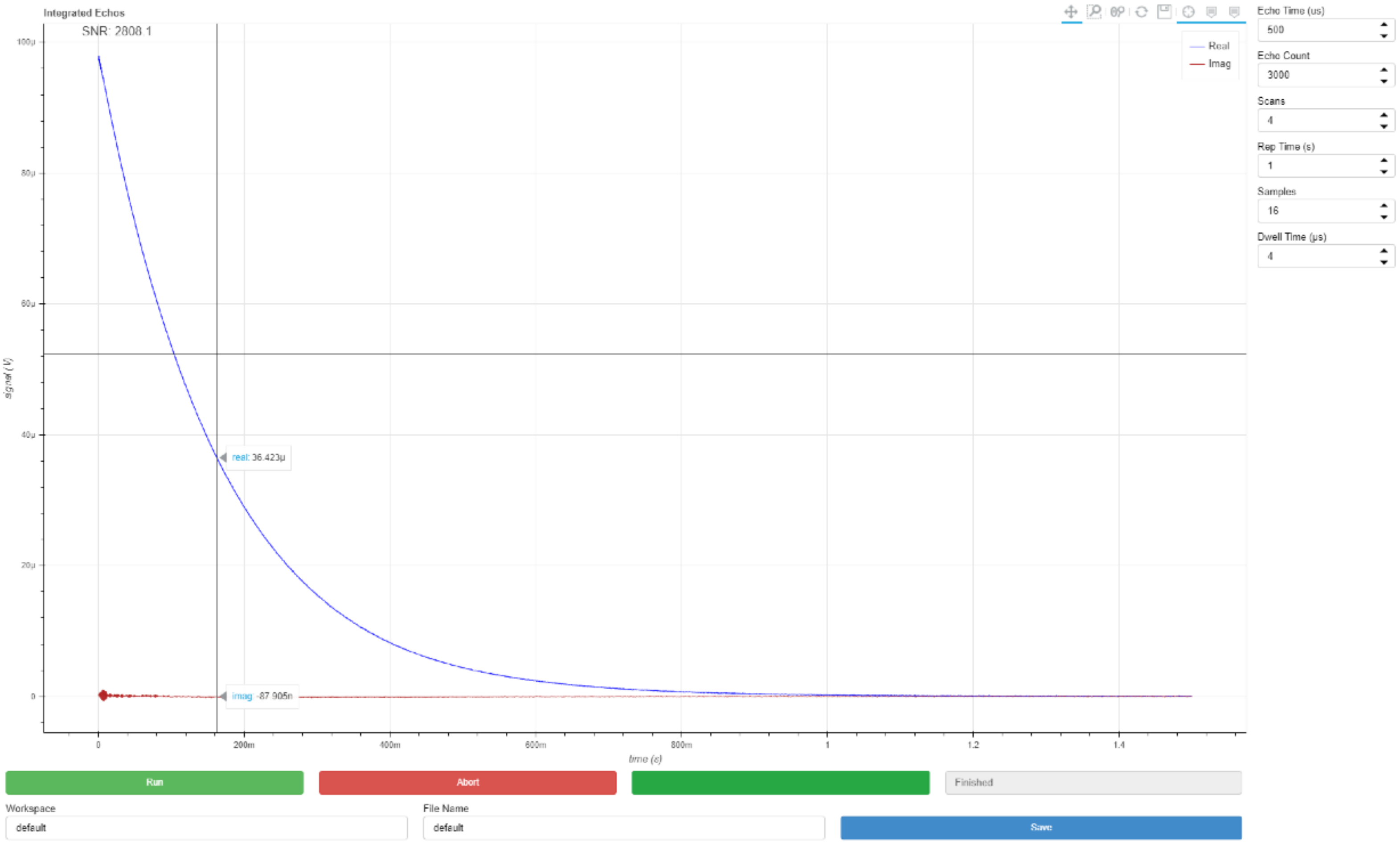
Scans: 4
Rep Time (s): 0.5
Samples: 10000
Dwell Time (µs): 10
Acq. Delay (µs): 50
Finished
Workspace: default
File Name: default

3.2.10 CPMG

This experiment runs a Carr-Purcell-Meiboom-Gill pulse sequence, repeated “Scans” times with 2 or 4 step phase cycling with the following parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans. Use 2 or a multiple of 4 scans for best results.
- Rep Time - time waited between scans, may need to be increased for samples with a long T1 recovery time (e.g. pure water).
- Samples- number of complex samples acquired per echo.
- Dwell Time - time between samples.
- Echo Time - time between 180 degree RF pulses, determines the time between data point on the *Integrated Echos* plot.
- Echo Count - number of echos, determines number of points on the *Integrated Echos* plot.

Note: frequency and pulse power/width are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.



Echo Time (us): 500

Echo Count: 3000

Scans: 4

Rep Time (s): 1

Samples: 16

Dwell Time (µs): 4

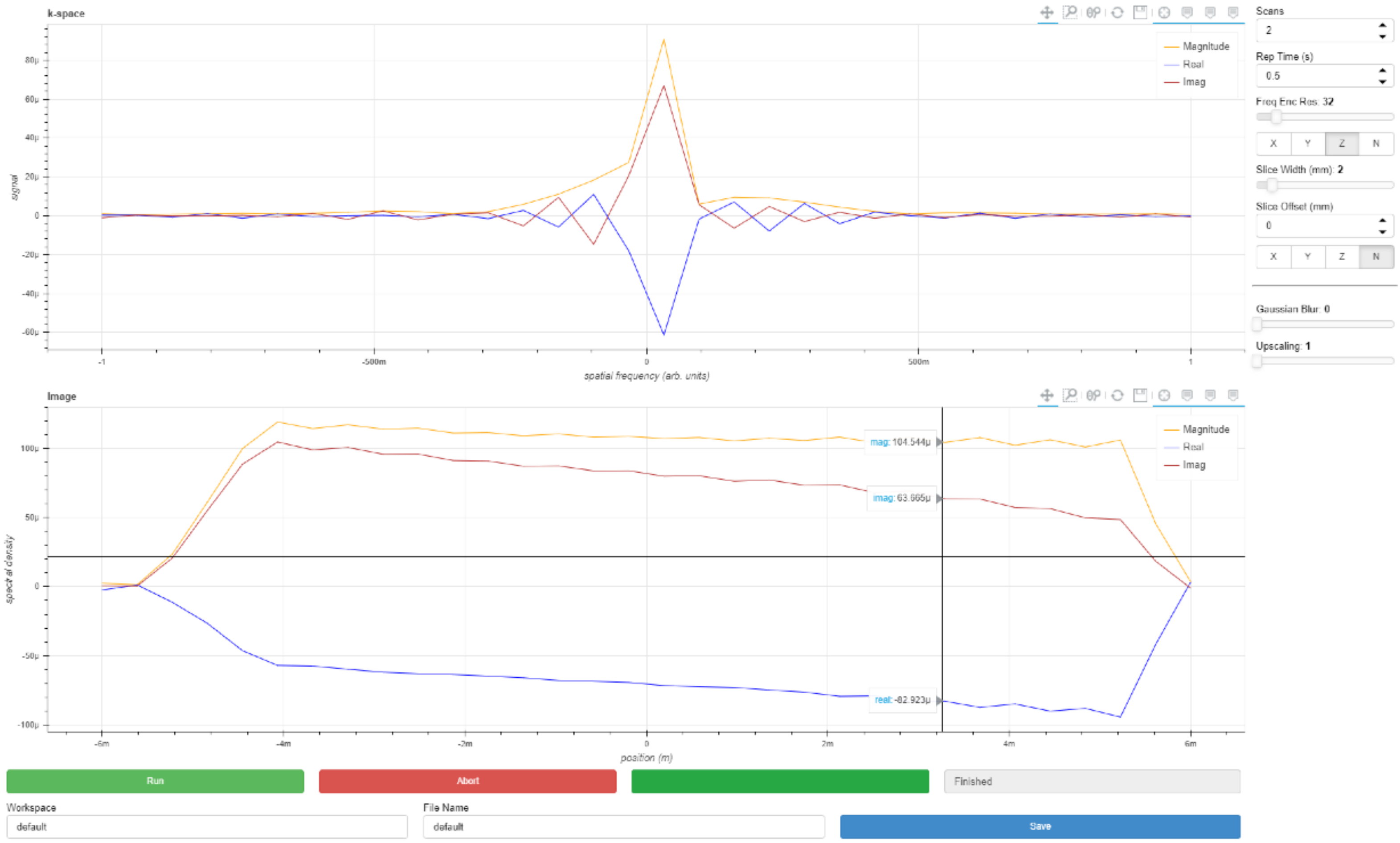
Workspace: default

File Name: default

3.2.11 1D SE

This experiment runs a Spin Echo pulse sequence with a frequency encoding gradient for 1D projection imaging, and optionally using soft 90 pulse with slice gradient for slice selection (can be applied along the same direction as the frequency encode gradient to measure the slice profile). Parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans.
- Rep Time - time waited between scans, may need to be increased for samples with a long T1 recovery time (e.g. pure water).
- Freq Enc Res - desired spatial resolution of the image along the frequency encode axis.
- Freq Enc Axis - selects which gradient to use for frequency encoding, or no gradient if *N*.
- Slice Width - desired spatial width of the slice.
- Slice Offset - desired spatial offset of slice along the slice axis.
- Slice Axis - selects which gradient to use for slicing, or no gradient if *N*. The experiment will use a hard 90 pulse when this option is set to *N*.



Scans: 2

Rep Time (s): 0.5

Freq Enc Res: 32

X Y [✓ Z] N

Slice Width (mm): 2

Slice Offset (mm): 0

X Y Z [✓ N]

Gaussian Blur: 0

Upscaling: 1

Finished

Workspace: default

File Name: default

The following post processing parameters are for smoothing and scaling the data:

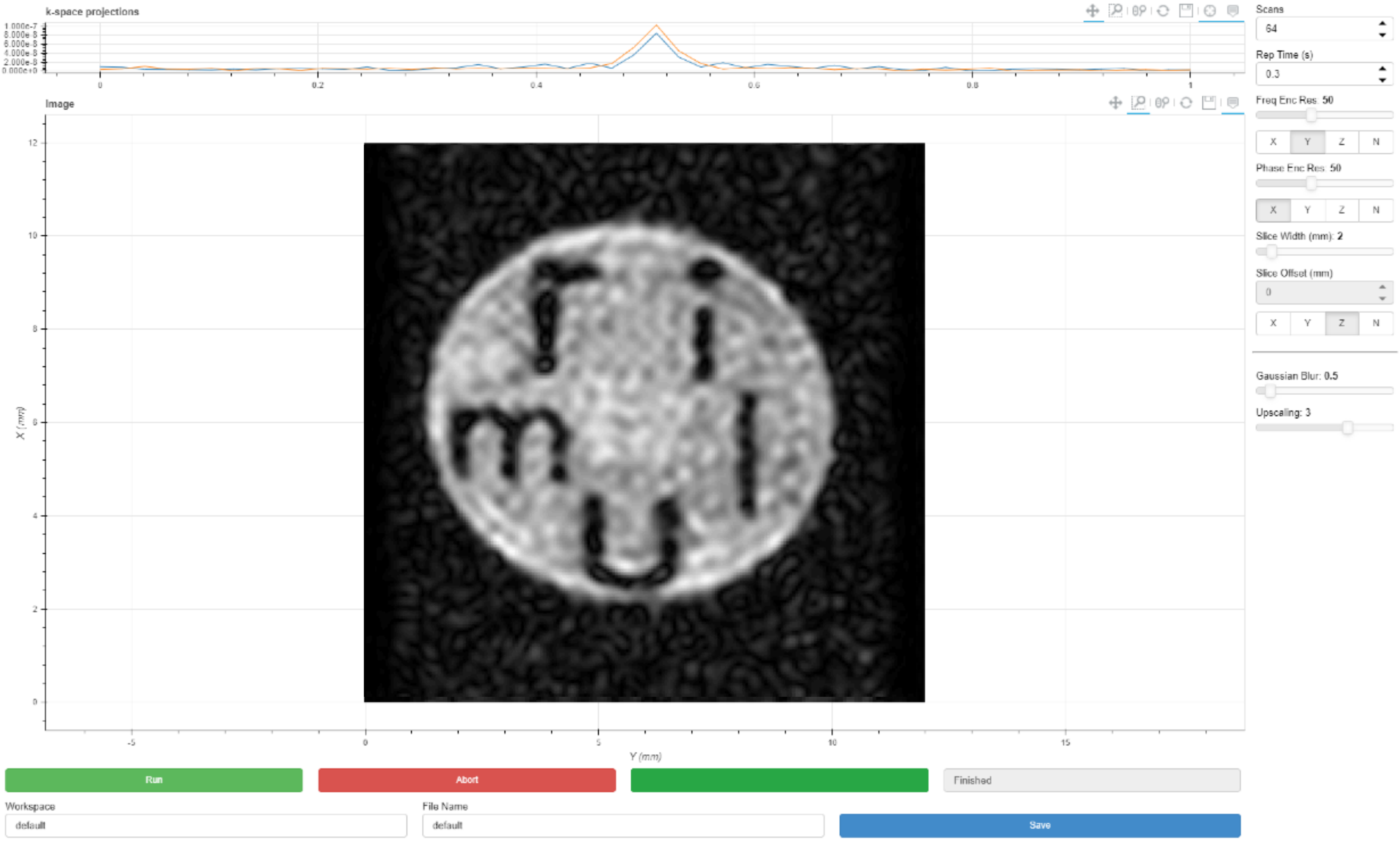
- Gaussian Blur - windows the data prior to Fourier reconstruction to filter out high frequency artefacts and increase SNR at the expense of resolution. Use 0 for no blurring.
- Upscaling - zero fills the data prior to Fourier reconstruction to reduce pixellation and give a smoother image. Use 1 for no upscaling.

Note: frequency, pulse power/width, and shim settings are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.

3.2.12 2D RARE

This experiment runs a RARE pulse sequence with optional slicing, frequency encode, and phase encode for either 2D projection or 2D slice imaging. Parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans.
- Rep Time - time waited between scans, may need to be increased for samples with a long T1 recovery time (e.g. pure water).
- Freq Enc Res - desired spatial resolution of the image along the frequency encode axis.
- Freq Enc Axis - selects which gradient to use for frequency encoding, or no gradient if *N*.
- Phase Enc Res - desired spatial resolution of the image along the phase encode axis.
- Phase Enc Axis - selects which gradient to use for phase encoding, or no gradient if *N*.
- Slice Width - desired spatial width of the slice.
- Slice Offset - not supported at time of writing, for more information please contact Resonint.
- Slice Axis - selects which gradient to use for slicing, or no gradient if *N*. The experiment will use a hard 90 pulse when this option is set to *N*.



Scans
64
Rep Time (s)
0.3
Freq Enc Res: 50
Phase Enc Res: 50
Slice Width (mm): 2
Slice Offset (mm)
0
Gaussian Blur: 0.5
Upscaling: 3
Finished
Workspace
default
File Name
default

The following post processing parameters are for smoothing and scaling the data:

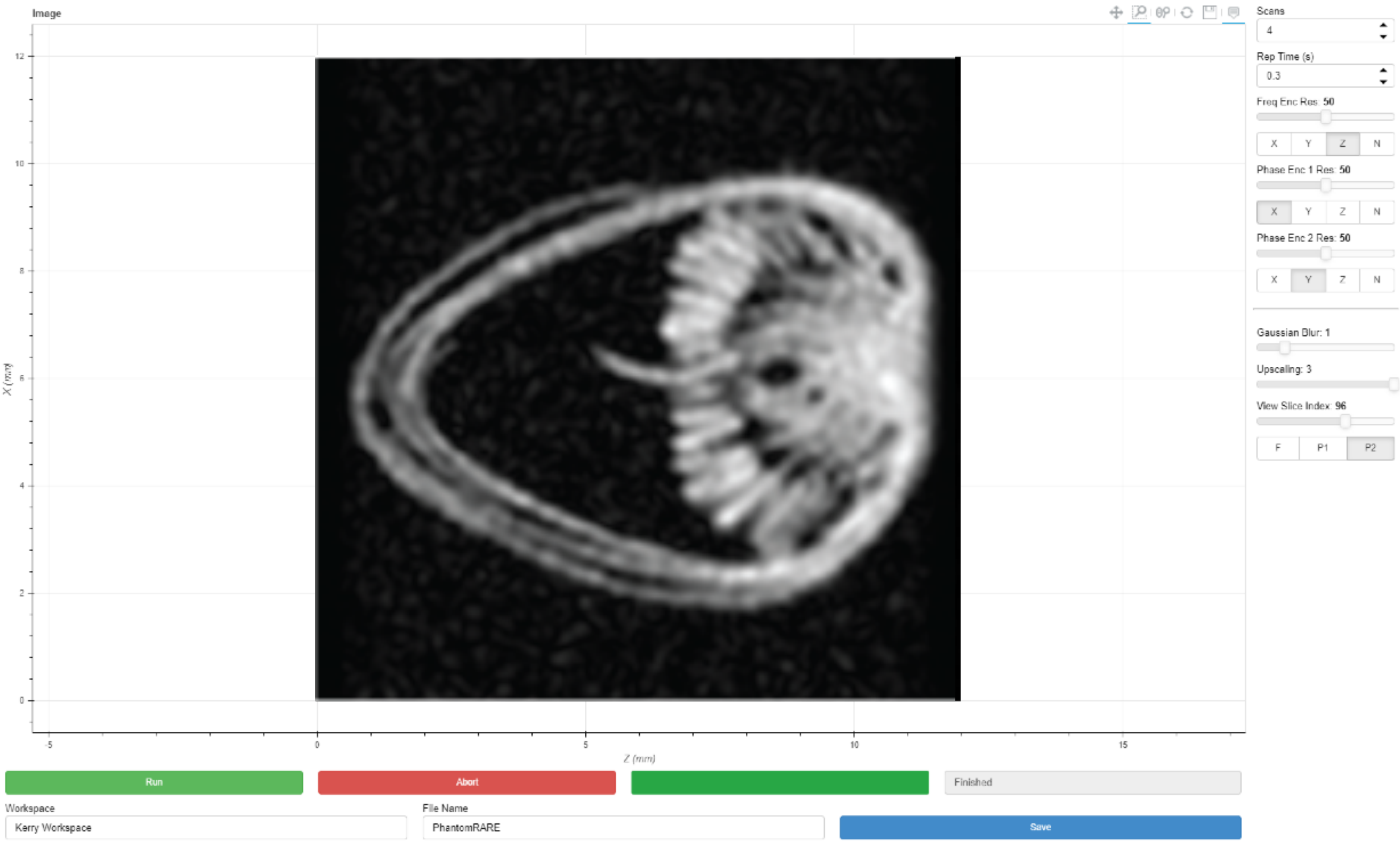
- Gaussian Blur - windows the data prior to Fourier reconstruction to filter out high frequency artefacts and increase SNR at the expense of resolution. Use 0 for no blurring.
- Upscaling - zero fills the data prior to Fourier reconstruction to reduce pixellation and give a smoother image. Use 1 for no upscaling.

Note: frequency, pulse power/width, and shim settings are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.

3.2.13 3D RARE

This experiment runs a RARE pulse sequence with frequency encode along one axis and phase encode along two axes. The number of echos in the CPMG sequence is set by *Phase Enc 2 Res* and the whole CPMG sequence is repeated *Phase Enc 1 Res* times, with appropriate phase gradient pulses. Parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans.
- Rep Time - time waited between scans, may need to be increased for samples with a long T1 recovery time (e.g. pure water).
- Freq Enc Res - desired spatial resolution of the image along the frequency encode axis.
- Freq Enc Axis - selects which gradient to use for frequency encoding, or no gradient if *N*.
- Phase Enc 1 Res - selects which gradient to use for the first phase encoding, or no gradient if *N*.
- Phase Enc 1 Axis - selects which gradient to use for phase encoding, or no gradient if *N*.
- Phase Enc 2 Res - desired spatial resolution of the image along the second phase encode axis.
- Phase Enc 2 Axis - selects which gradient to use for the second phase encoding, or no gradient if *N*.



Scans: 4

Rep Time (s): 0.3

Freq Enc Res: 50

X Y [✓ Z] N

Phase Enc 1 Res: 50

[✓ X] Y Z N

Phase Enc 2 Res: 50

X [✓ Y] Z N

Gaussian Blur: 1

Upscaling: 3

View Slice Index: 96

F P1 [✓ P2]

Workspace: Kerry Workspace

File Name: PhantomRARE

The following post processing parameters are for smoothing, scaling, and viewing the data:

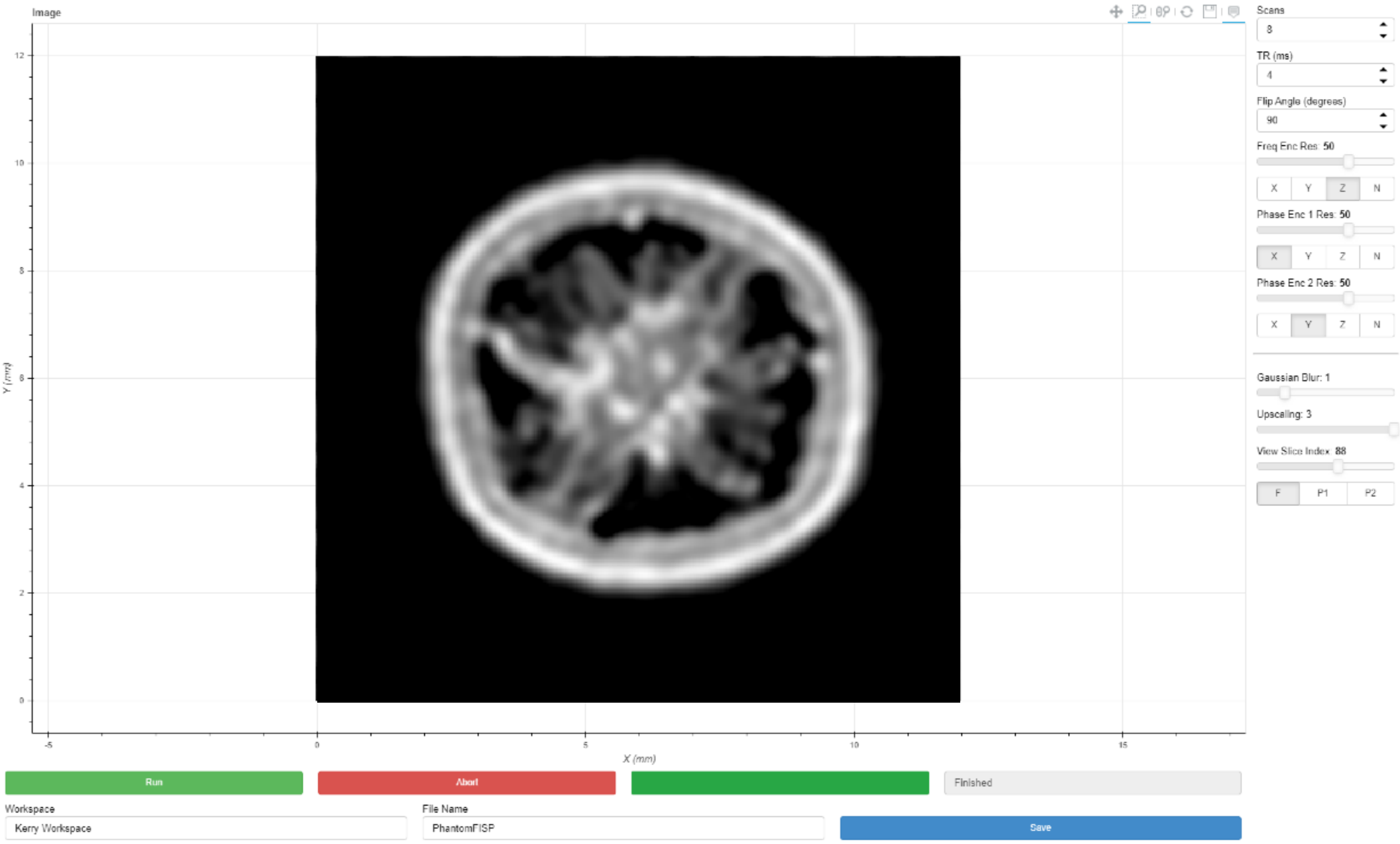
- Gaussian Blur - windows the data prior to Fourier reconstruction to filter out high frequency artefacts and increase SNR at the expense of resolution. Use 0 for no blurring.
- Upscaling - zero fills the data prior to Fourier reconstruction to reduce pixellation and give a smoother image. Use 1 for no upscaling.
- View Slice index - set the slice axis with the F/P1/P2 radio buttons (physical axis will depend on above settings) and drag the *View Slice Index* slider to move the slice plane through the 3D data.

Note: frequency, pulse power/width, and shim settings are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.

3.2.14 3D FISP

This experiment runs a FISP (also called GRASS) pulse sequence with frequency encode along one axis and phase encode along two axes. Parameters:

- Scans - can be used to improve the signal-to-noise ratio (SNR) by averaging multiple scans.
- TR - time between RF pulses; affects T1 contrast and pulse sequence duration.
- Flip Angle - sets the flip angle of the RF pulse used.
- Freq Enc Res - desired spatial resolution of the image along the frequency encode axis.
- Freq Enc Axis - selects which gradient to use for frequency encoding, or no gradient if *N*.
- Phase Enc 1 Res - desired spatial resolution of the image along the first phase encode axis.
- Phase Enc 1 Axis - selects which gradient to use for the first phase encoding, or no gradient if *N*.
- Phase Enc 2 Res - desired spatial resolution of the image along the second phase encode axis.
- Phase Enc 2 Axis - selects which gradient to use for the second phase encoding, or no gradient if *N*.



Scans: 8

TR (ms): 4

Flip Angle (degrees): 90

Freq Enc Res: 50 — Z

Phase Enc 1 Res: 50 — X

Phase Enc 2 Res: 50 — Y

Gaussian Blur: 1

Upscaling: 3

View Slice Index: 88 — F

Workspace: Kerry Workspace

File Name: PhantomFISP

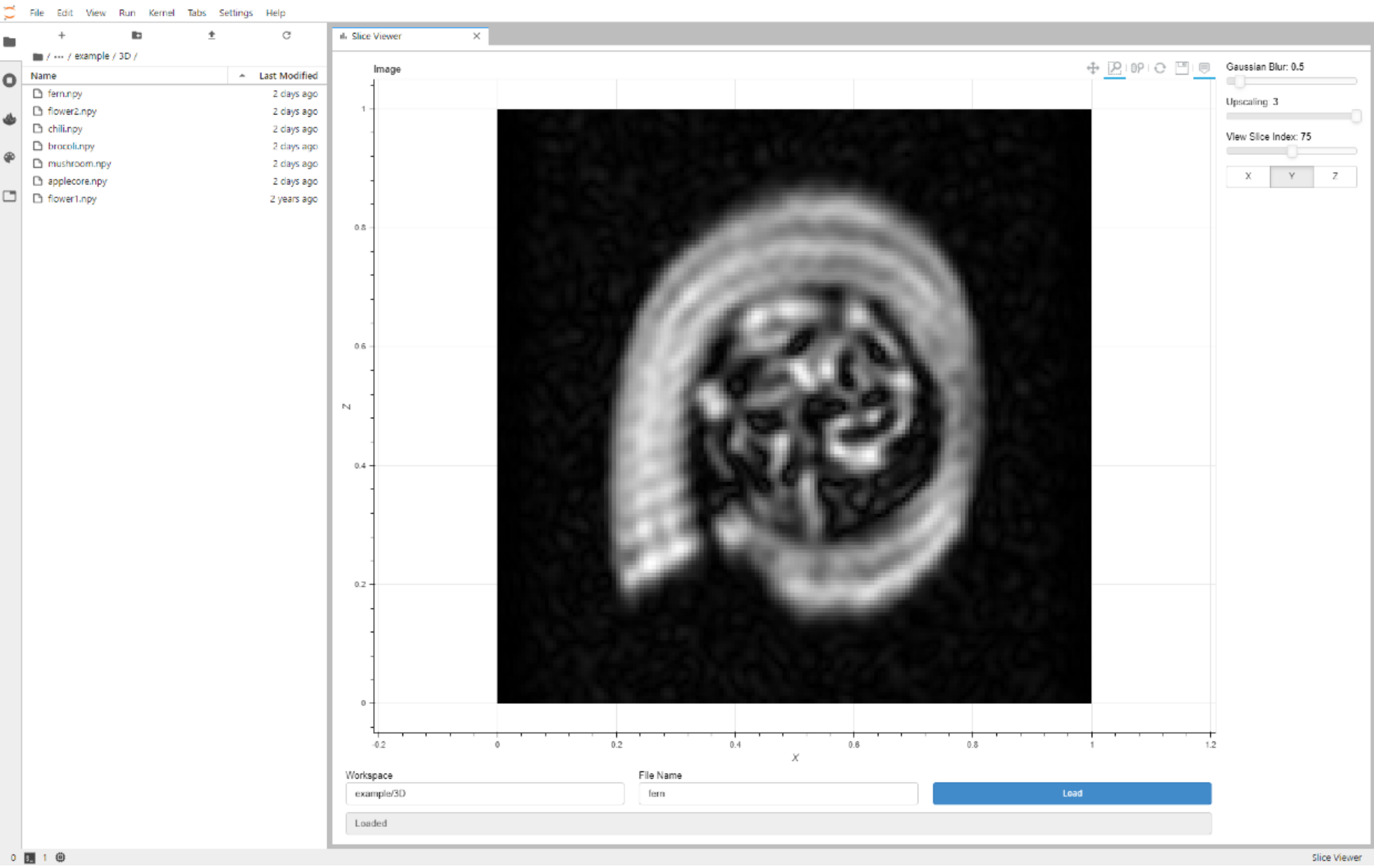
The following post processing parameters are for smoothing, scaling, and viewing the data:

- Gaussian Blur - windows the data prior to Fourier reconstruction to filter out high frequency artefacts and increase SNR at the expense of resolution. Use 0 for no blurring.
- Upscaling - zero fills the data prior to Fourier reconstruction to reduce pixellation and give a smoother image. Use 1 for no upscaling.
- View Slice index - set the slice axis with the F/P1/P2 radio buttons (physical axis will depend on above settings) and drag the *View Slice Index* slider to move the slice plane through the 3D data.

Note: frequency, pulse power/width, and shim settings are read from the global system parameter files every time the experiment is run, and cannot be set manually in the dashboard.

3.2.15 Slice Viewer

Data saved from *3D RARE* or *3D FISP* experiments can be loaded to view in the slice viewer. Specify *Workspace* and *Filename* as when saving and click *Load*.



/ ··· / example / 3D /

Name	Last Modified
fern.npy	2 days ago
flower2.npy	2 days ago
chili.npy	2 days ago
brocoli.npy	2 days ago
mushroom.npy	2 days ago
applecore.npy	2 days ago
flower1.npy	2 years ago

Gaussian Blur: 0.5

Upscaling: 3

View Slice Index: 75

Workspace: example/3D

File Name: fern

Loaded

The following post processing parameters are for smoothing, scaling, and viewing the data:

- Gaussian Blur - windows the data prior to Fourier reconstruction to filter out high frequency artefacts and increase SNR at the expense of resolution. Use 0 for no blurring.
- Upscaling - zero fills the data prior to Fourier reconstruction to reduce pixellation and give a smoother image. Use 1 for no upscaling.
- View Slice index - set the slice axis with the X/Y/Z radio buttons (physical axis will depend on experiment settings) and drag the *View Slice Index* slider to move the slice plane through the 3D data.

4. Jupyter Notebooks

Jupyter Notebooks combine descriptive text, Python code snippets, and data visualisation into a single interactive document, allowing for flexible experimentation. The ilumr system can be controlled completely through the Python API library named *matipo*. To learn how to use this API, it is recommended to work through the example notebooks provided, as is described in the following sections. The python version is 3.6, and a number of useful third party libraries have been preinstalled, including:

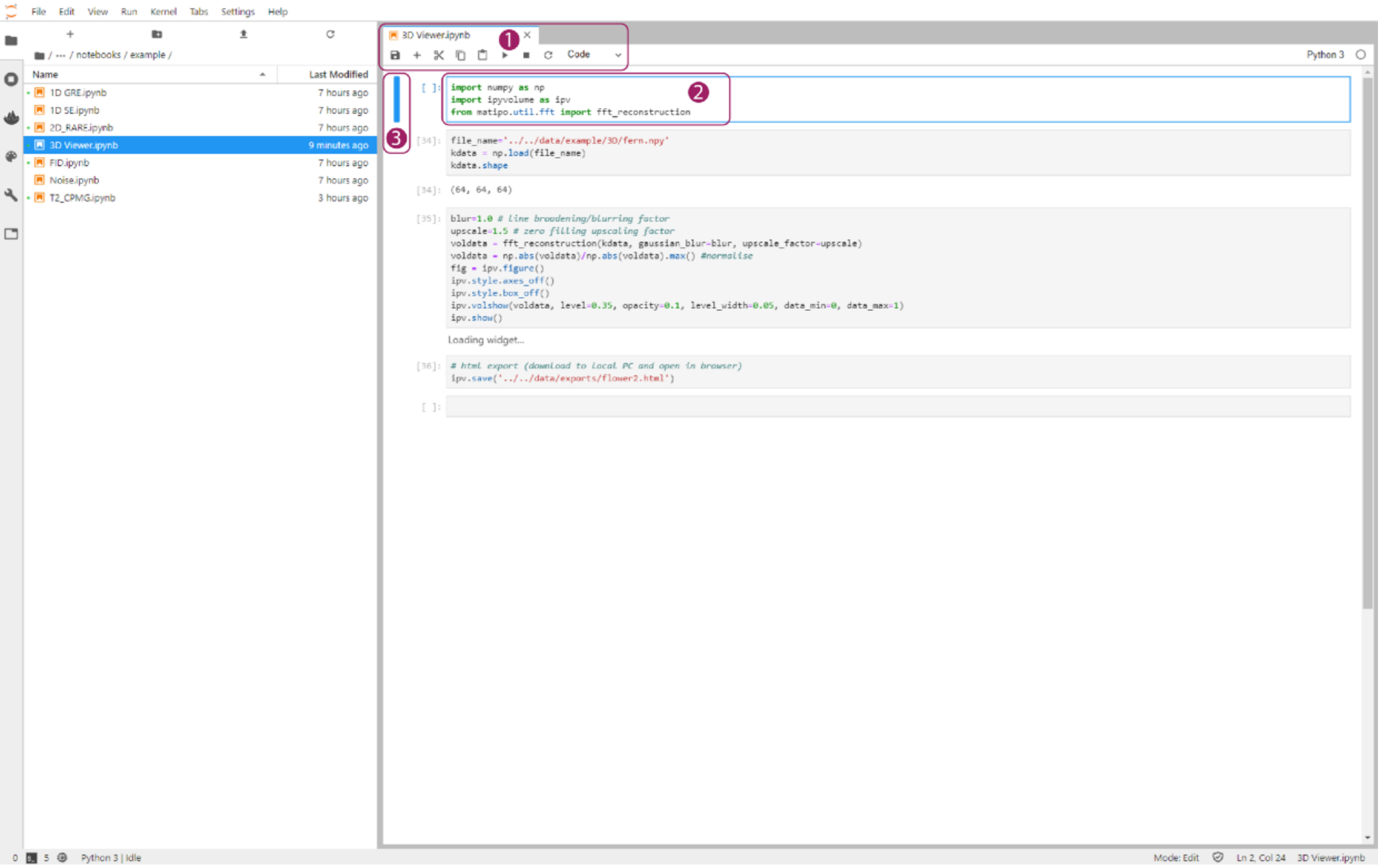
- NumPy - Powerful numerical computing
- SciPy - Collection of tools for science & engineering
- Matplotlib - Plotting tools
- Bokeh - Interactive plotting/visualisation
- IPyVolume - 3D volume data rendering
- IPyWidgets - Standard widgets for interactive notebooks

For more information on jupyter notebooks, the official documentation can be found at https://jupyterlab.readthedocs.io/en/1.2.x/user/notebook.html

4.1 Running a Notebook

Some example notebooks are provided in the *user/notebooks/example/* directory. Notebooks have the *.ipynb* extension and can be opened by double clicking in the file browser.

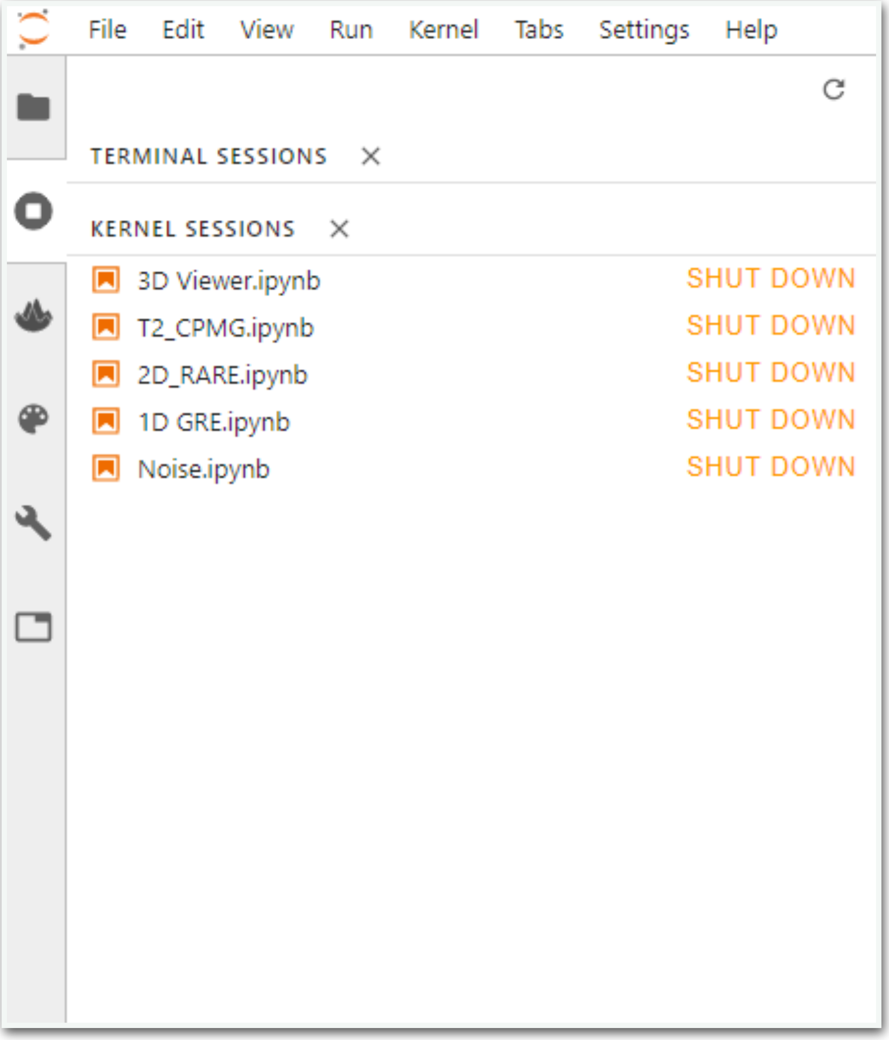
Clicking the play button (1.) at the top left (or using the *shift+enter* shortcut) will execute the cells in order. Cells can be re-executed by clicking on the cells (2.) and clicking the play button (or *shift+enter*). The bar (3.) shows the currently selected cell, read on with section 4.2 for an example of how to use the 3D Viewer notebook.



Name	Last Modified
1D GRE.ipynb	7 hours ago
1D SE.ipynb	7 hours ago
2D_RARE.ipynb	7 hours ago
3D Viewer.ipynb	9 minutes ago
FID.ipynb	7 hours ago
Noise.ipynb	7 hours ago
T2_CPMG.ipynb	3 hours ago

```
[ ]:  import numpy as np
      import ipyvolume as ipv
      from matipo.util.fft import fft_reconstruction

[34]: file_name='../../data/example/3D/fern.npy'
      kdata = np.load(file_name)
      kdata.shape

[34]: (64, 64, 64)

[35]: blur=1.0 # line broadening/blurring factor
      upscale=1.5 # zero filling upscaling factor
      voldata = fft_reconstruction(kdata, gaussian_blur=blur, upscale_factor=upscale)
      voldata = np.abs(voldata)/np.abs(voldata).max() #normalise
      fig = ipv.figure()
      ipv.style.axes_off()
      ipv.style.box_off()
      ipv.volshow(voldata, level=0.35, opacity=0.1, level_width=0.05, data_min=0, data_max=1)
      ipv.show()

      Loading widget...

[36]: # html export (download to local PC and open in browser)
      ipv.save('../../data/exports/flower2.html')

[ ]:
```

Note: having many notebooks open at once can use a lot of system memory and slow it down, if you notice issues you can use the *running* sidebar as shown below to shutdown the running kernels of unused notebooks and free up system resources.



TERMINAL SESSIONS ✕

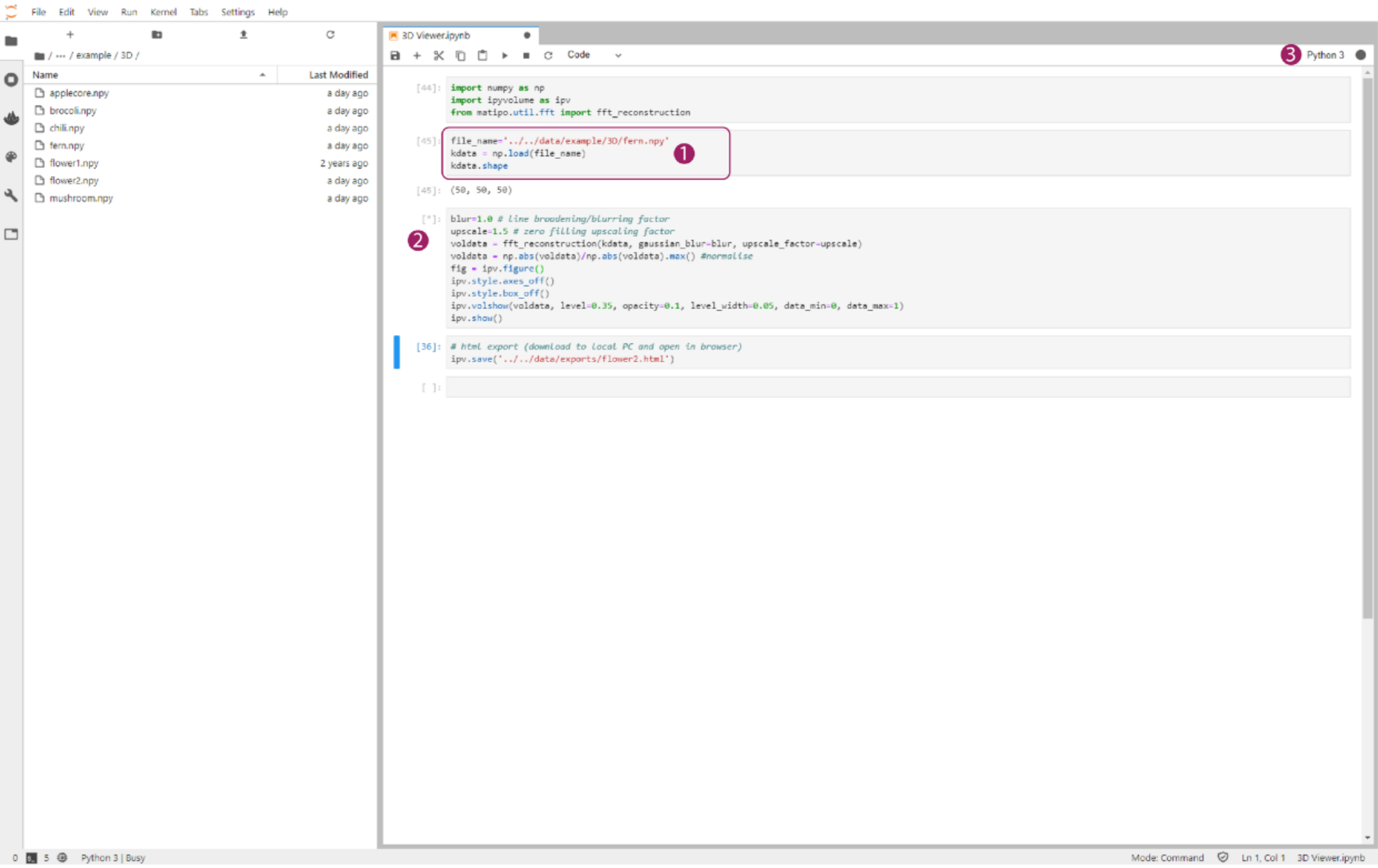
KERNEL SESSIONS ✕

3D Viewer.ipynb	SHUT DOWN
T2_CPMG.ipynb	SHUT DOWN
2D_RARE.ipynb	SHUT DOWN
1D GRE.ipynb	SHUT DOWN
Noise.ipynb	SHUT DOWN

To create new notebooks, click the + button in the file browser (top left) and click python3 under the notebook heading of the launcher window that opens. Alternately you can *right click->duplicate* an existing notebook (or *right click->copy* and *right-click->paste*), rename the copy, and open it for editing.

4.2 3D Viewer Notebook

Double click the 3D Viewer notebook to open it in a new tab. Navigate to the *data/example/3D* folder and choose a data set to load. For this example we are loading the fern data set and have entered *fern.npy* into the file name as shown in the image below (1.). Run these cells by clicking the play button or using the *shift* + *enter* keys. When a cell is being run, an Asterix will appear next to it (2.) and the busy icon will be shown. (3.)

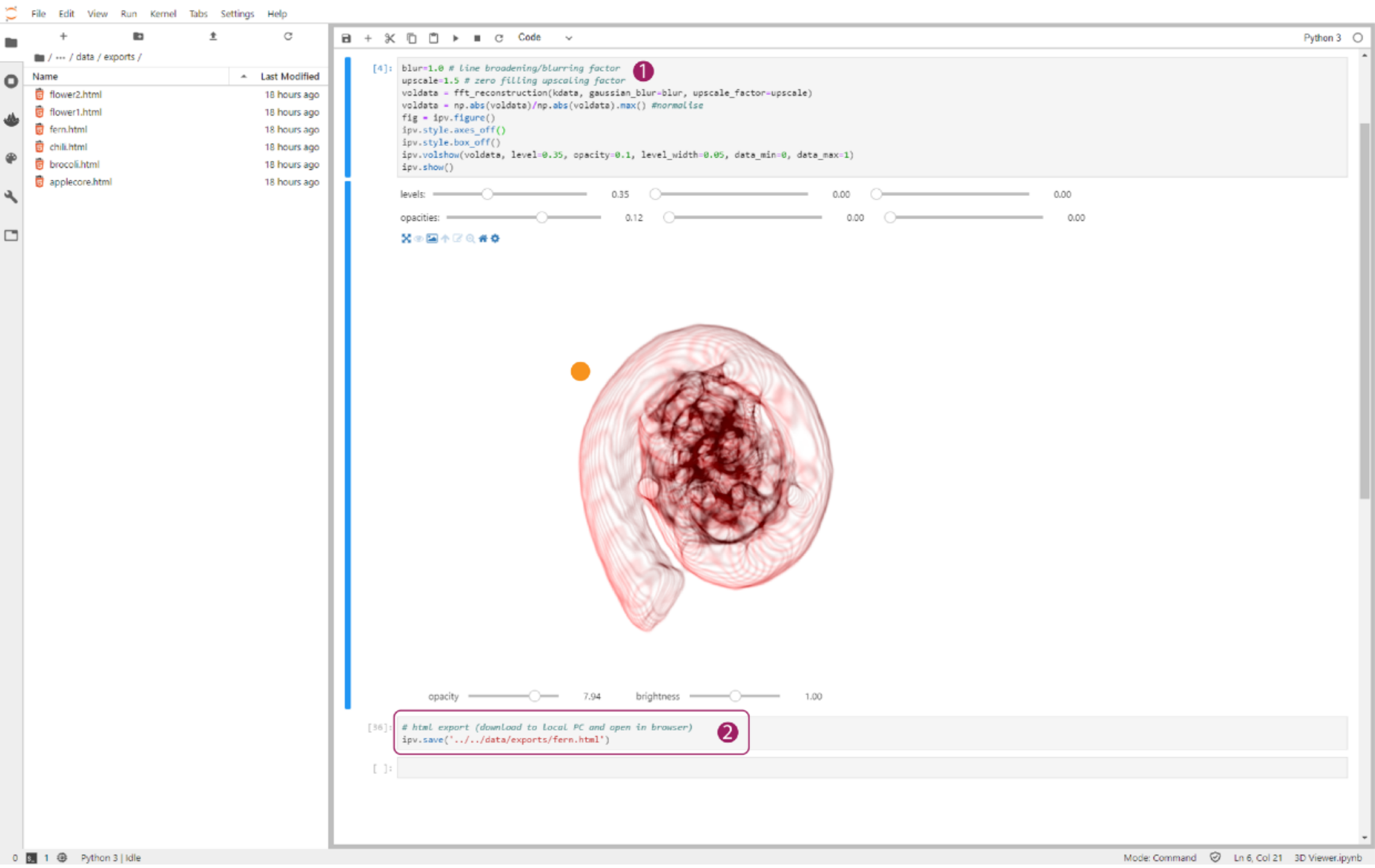


Name	Last Modified
applecore.npy	a day ago
brocoli.npy	a day ago
chili.npy	a day ago
fern.npy	a day ago
flower1.npy	2 years ago
flower2.npy	a day ago
mushroom.npy	a day ago

```
[44]: import numpy as np
      import ipyvolume as ipv
      from matipo.util.fft import fft_reconstruction

[45]: file_name='../../data/example/3D/fern.npy'
      kdata = np.load(file_name)
      kdata.shape

[45]: (50, 50, 50)

[*]:  blur=1.0 # line broadening/blurring factor
      upscale=1.5 # zero filling upscaling factor
      voldata = fft_reconstruction(kdata, gaussian_blur=blur, upscale_factor=upscale)
      voldata = np.abs(voldata)/np.abs(voldata).max() #normalise
      fig = ipv.figure()
      ipv.style.axes_off()
      ipv.style.box_off()
      ipv.volshow(voldata, level=0.35, opacity=0.1, level_width=0.05, data_min=0, data_max=1)
      ipv.show()

[36]: # html export (download to local PC and open in browser)
      ipv.save('../../data/exports/flower2.html')

[ ]:
```

As shown below, running section (1.) will generate a 3D image using IPyVolume. Click and drag in the window area to rotate and manipulate the plot. You can also move the sliders to increase levels of contrast and opacity.

Running the final cell block (2.) will package the data into a single HTML file which can be downloaded and viewed in a browser.



/ ··· / data / exports /

Name	Last Modified
flower2.html	18 hours ago
flower1.html	18 hours ago
fern.html	18 hours ago
chili.html	18 hours ago
brocoli.html	18 hours ago
applecore.html	18 hours ago

```
[4]: blur=1.0 # line broadening/blurring factor
     upscale=1.5 # zero filling upscaling factor
     voldata = fft_reconstruction(kdata, gaussian_blur=blur, upscale_factor=upscale)
     voldata = np.abs(voldata)/np.abs(voldata).max() #normalise
     fig = ipv.figure()
     ipv.style.axes_off()
     ipv.style.box_off()
     ipv.volshow(voldata, level=0.35, opacity=0.1, level_width=0.05, data_min=0, data_max=1)
     ipv.show()
```

levels: 0.35 0.00 0.00

opacities: 0.12 0.00 0.00

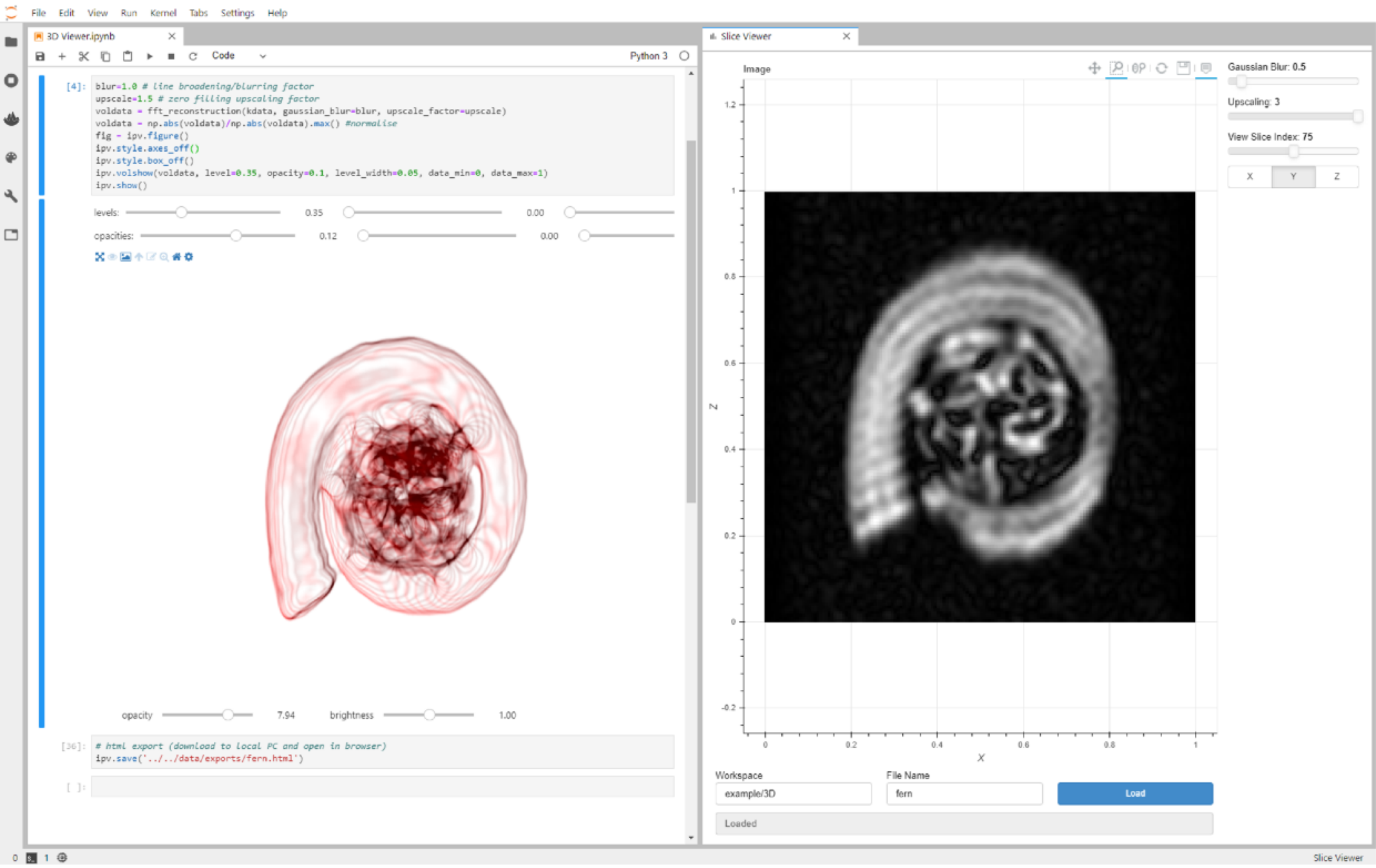
opacity 7.94 brightness 1.00

```
[36]: # html export (download to local PC and open in browser)
      ipv.save('../../data/exports/fern.html')

[ ]:
```

0 1 Python 3 | Idle

Mode: Command Ln 6, Col 21 3D Viewer.ipynb

The image below shows how the 3D Viewer notebook and the Slice Viewer dashboard App can be run side by side to provide both 3D and 2D views of the same data set.



```
[4]: blur=1.0 # line broadening/blurring factor
     upscale=1.5 # zero filling upscaling factor
     voldata = fft_reconstruction(kdata, gaussian_blur=blur, upscale_factor=upscale)
     voldata = np.abs(voldata)/np.abs(voldata).max() #normalise
     fig = ipv.figure()
     ipv.style.axes_off()
     ipv.style.box_off()
     ipv.volshow(voldata, level=0.35, opacity=0.1, level_width=0.05, data_min=0, data_max=1)
     ipv.show()
```

levels: 0.35 0.00

opacities: 0.12 0.00

opacity 7.94 brightness 1.00

```
[36]: # html export (download to local PC and open in browser)
      ipv.save('../../data/exports/fern.html')
```

Gaussian Blur: 0.5

Upscaling: 3

View Slice Index: 75

Workspace: example/3D

File Name: fern

Loaded

Information and help on running the other example notebooks is contained within each notebook. Open and step through these to get a better understanding of how notebooks can be used to control the ilumr.

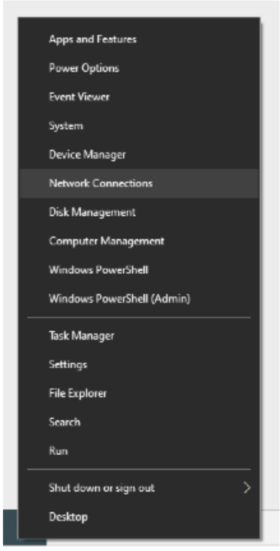
5. Further notes

To setup a direct ethernet connection with your PC, update the ilumr software, or change the RF probe please read through the following steps.

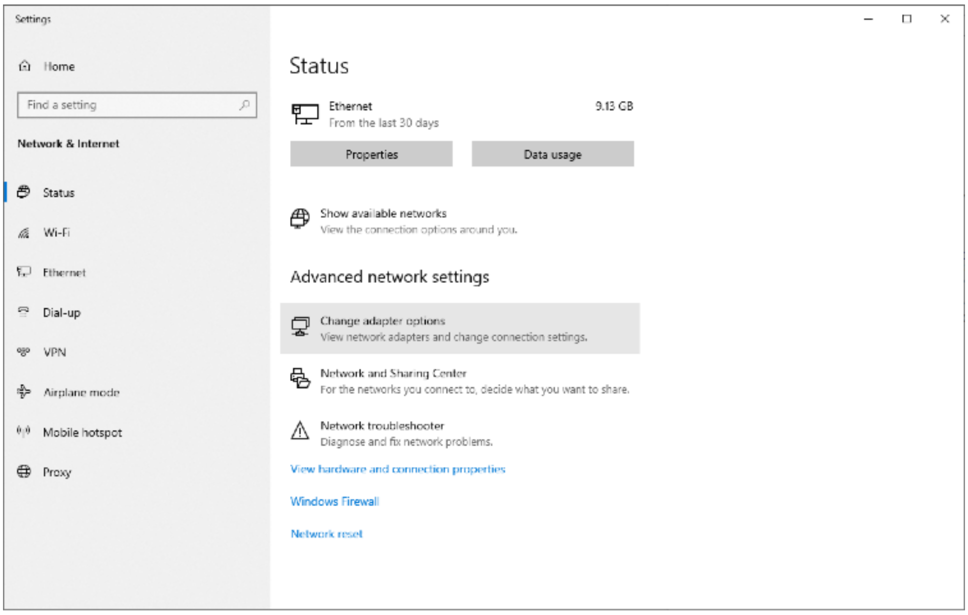
5.1 Setting up a direct ethernet connection

For Windows 10:

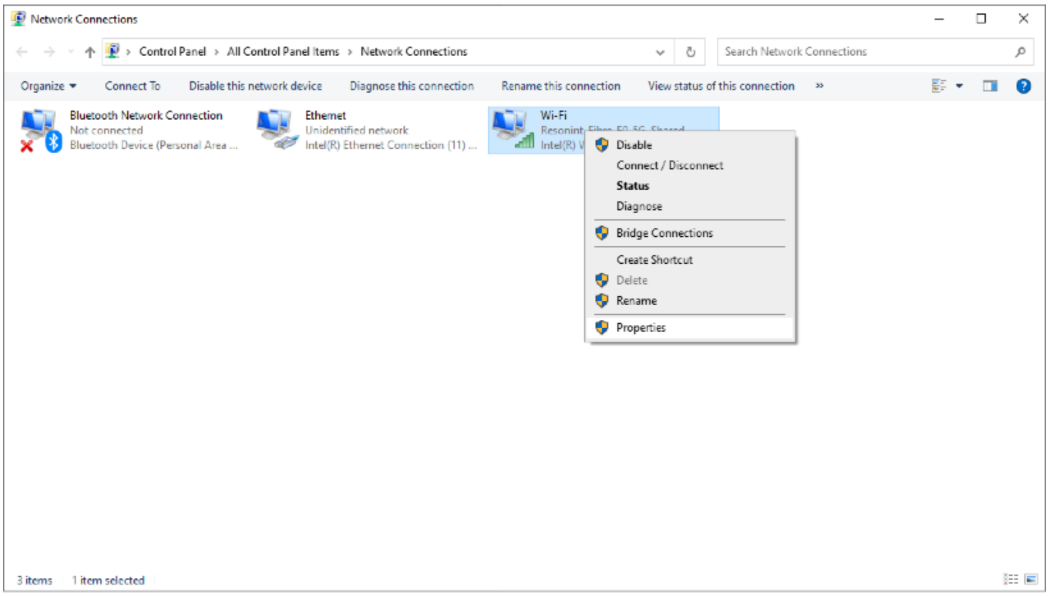
1. Right click start menu - Network Connections.



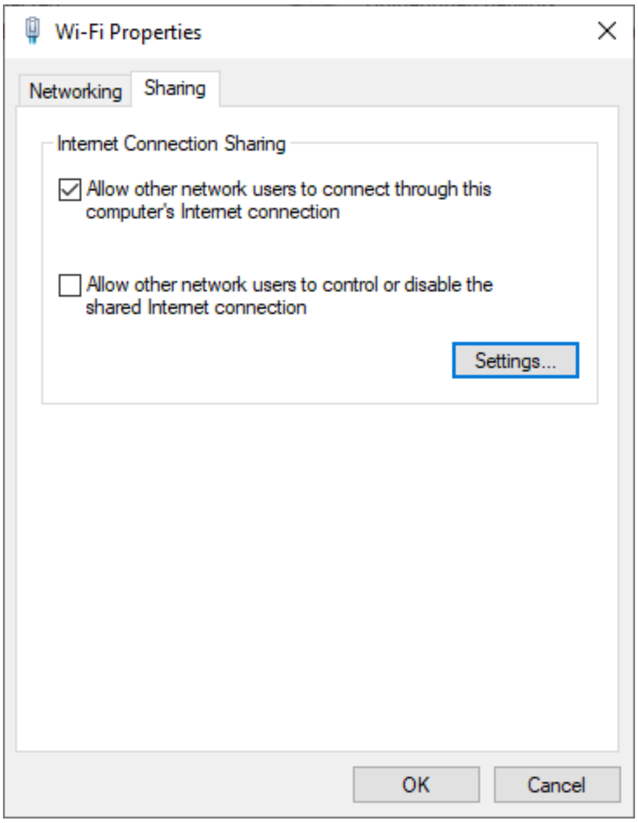
2. Click Change Adapter Options under Advanced networks settings.


Settings
Home
Find a setting
Network & Internet
Status
Wi-Fi
Ethernet
Dial-up
VPN
Airplane mode
Mobile hotspot
Proxy
Status
Ethernet
From the last 30 days
9.13 GB
Properties
Data usage
Show available networks
View the connection options around you.
Advanced network settings
Change adapter options
View network adapters and change connection settings.
Network and Sharing Center
For the networks you connect to, decide what you want to share.
Network troubleshooter
Diagnose and fix network problems.
View hardware and connection properties
Windows Firewall
Network reset

3. Right click the adapter that has internet and select Properties



4. Click the Sharing tab and check "Allow other network users to connect through this computer's Internet connection" and select ethernet on the dropdown menu (if visible).



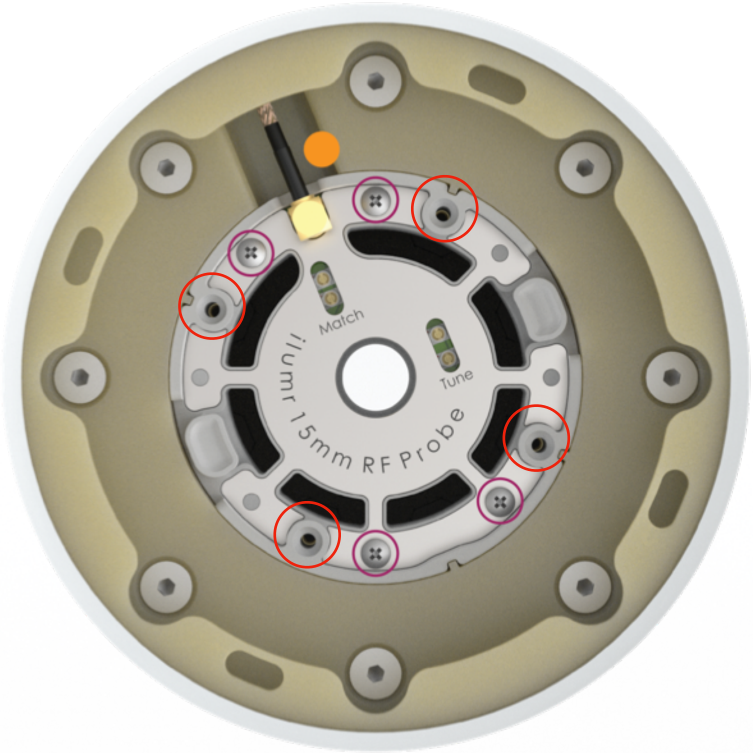
☑ Allow other network users to connect through this computer's Internet connection

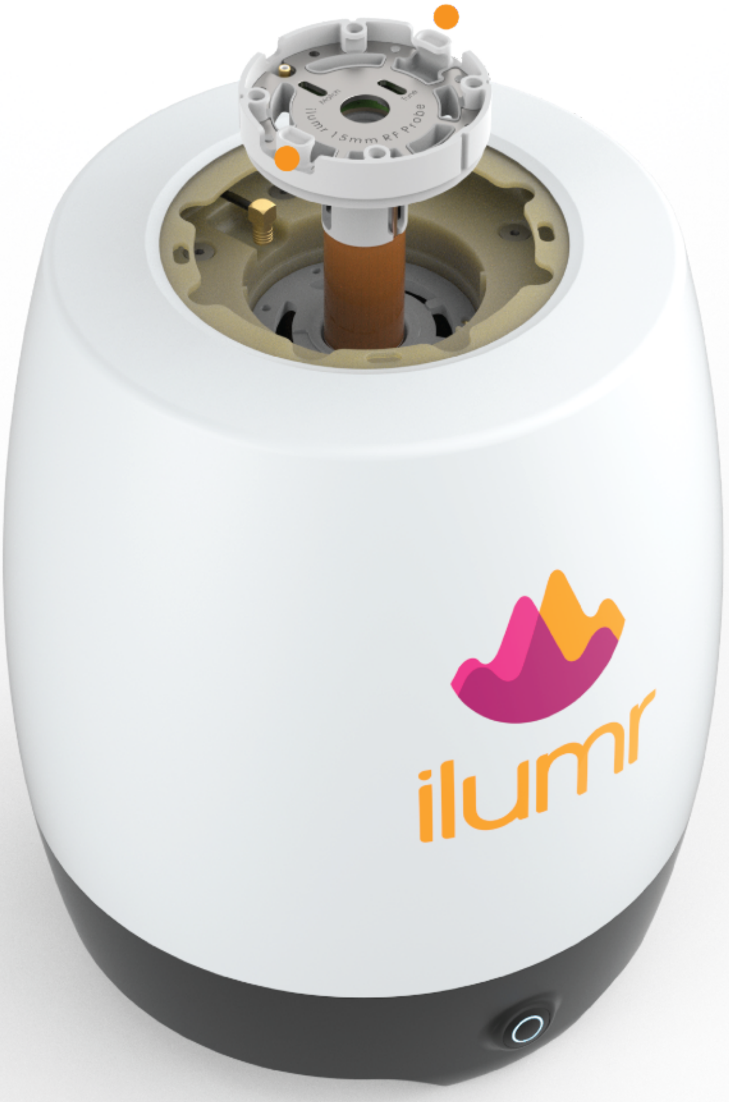
□ Allow other network users to control or disable the shared Internet connection

5.2 Changing the RF probe

If a 15mm RF probe has been supplied, it can be swapped using the following steps.

1. Insert the supplied blanking tool into the RF probe, this ensures that fasteners cannot be dropped down the gradient cooling air vents. Remove the 4 fasteners as shown in the image below will allow you remove the entire Gradient/RF probe assembly. To just swap the RF probe, also remove the other 4 fasteners to unbolt it from the gradient
2. Disconnect the RF probe, orange dot in image below.





3. Using the tabs on each side of the probe, carefully pull it up out of the system. Take care to not apply any pressure to the RF shield.
4. Lower the 15mm RF probe into place, secure with the fasteners and reconnect the probe.
5. Open the FOV.yaml file in the Globals folder and set the value to 0.018 to increase the field of view for the larger probe.
6. Finally the pulse lengths will need to be recalibrated, follow the instructions in section (3.2.5) to calculate the required values for the 15mm probe.