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Rules of Conduct

- ✓ Do not leave a mess on the table. You work on the shared setup, respect other users.
- ✓ Use the laboratory computer **ONLY** for experiments, it's not your personal computer.
- ✓ Use the confocal setup's **LOG BOOK** to write down any changes in the setup. After you are done with experiments, return all the borrowed equipment to the original places and return the setup to the standard configuration (*CW laser, SP550 after the laser, air objective, LP650 before APD, no beamsplitter, LP600 before the spectrometer, AWG as MW source for pulsed measurements*).
- ✓ All Data files should be saved **ONLY** in the D:\Data folder. All jupyter notebook scripts should be **ONLY** in the C:\Data\Scripts folder.
- ✓ **Make data backup every Friday.**
- ✓ Any software installation should be approved by the setup responsible person.
- ✓ Any alignment changes should be approved by, and any errors should be reported to the setup responsible person.
- ✓ If you have any problems during measurements - check the manual's troubleshooting section or contact the setup responsible person.

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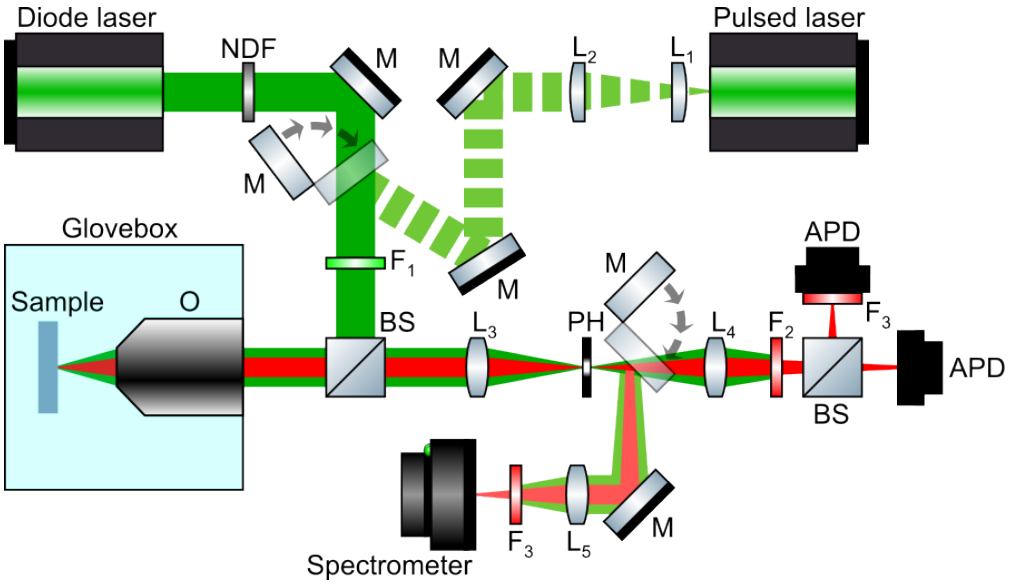
Setup description



Optical Table

#	Device	Company / Model	Comments
1.1	Green CW laser	Toptica Photonics / iBEAM-SMART-515-S	λ = 518 nm Max output power 100 mW
1.2	Optical fiber	Thorlabs / 460HP-Custom-Muc	PC?-APC
1.3	Collimator	Thorlabs / TC25APC-532	
2.1	Pulsed laser	NKT Photonics / SuperK EXTREME + SuperK VARIA	
2.2	Lens	Thorlabs / LA1951-A-ML	f = 25.4 mm
2.3	Lens	Thorlabs / LA1708-A-ML	f = 200 mm
3.1	Yellow CW laser	Newport / N-LYP-173	
4	Neutral density wheel	Thorlabs / NDC-50C-4M	
5	Filter	Thorlabs / FESH0550	
6	Beam sampler	Thorlabs / BSF20-B	
7	Power meter	Thorlabs / PM400 Sensor: S130C	
8	Stage	PI / P-527.3CL Newport / M-406	
9	Objective	Air: Olympus MPLAPON 50×/0.95 Oil: Leica HCX PL APO 100×/1.40	Working distance: 350 µm Working distance: 130 µm
10	Lens	Thorlabs / AC-254-060-A-ML	f = 60.0 mm
11	Pinhole	Thorlabs / P25D	d = 25 µm
12	Lens	Thorlabs / AC-254-060-A-ML	f = 60.0 mm
13	Filter	Thorlabs / FELH0650	
14	Beam splitter	Thorlabs / EBS1	
15	APD1	Excelitas / SPCM-AQRH-14 ?	Dead time: max 40 ns
16	Filter	Thorlabs / FESH0750	To remove APD afterglow effect.
17	APD2	Excelitas / SPCM-AQRH-14 ?	Dead time: max 40 ns
18	Flipping mirror	Thorlabs / MFF101/M	
19	Lens	Thorlabs / AC254-100-B-ML	f = 100.0 mm
20	Filter	Thorlabs / FELH0600	LP550 passes Raman peaks.
21	Spectrometer	Teledyne Princeton Instruments / CCD: PIXIS: 100B eXcelon (1340×100)	
22	Table	Thorlabs / Breadboard: B90120N Frame: ScienceDesk	Pressure < 80 PSI (5.5 bar)

23	Glovebox	SylaTech, custom model	10 mm thick Plexiglas, 900 mm x 500 mm x 500 mm, pressure regulator between 2-5 mbar

Hardware

	Pulse generator (copy)	Hewlett Packard 8012A Pulse Generator	Might cause artefacts during lifetime measurements if count rate is too high.
	Data acquisition	NI USB-6343 X Series Multifunction DAQ	
	Piezo controller	PI E-564.I3C	
	Arbitrary Waveform Generator	Tektronix AWG7122C	
	MW source	TTi TGR6000	
	Counter	FAST ComTec MCS6	Needs attenuation for the AWG sync channel.
	Switcher	Mini-Circuits Switch ZASWA-2-50DR+	
	MW amplifier (1.9-4.2 GHz)	MiniCircuit ZHL-16W-43+ Power supply should be 38 V and 4 A.	Max input 9 dBm (0,63 V). Gain 45 dB. Output 54 dBm (for max input).
	RF amplifier (1 – 4.2 GHz & 4.2+ GHz)	IFI ST181-20 Bands 1-4.2 GHz & 4.2-18 GHz	Gain 43 dB. Output 56 dBm (for 1 V).

Software and drivers

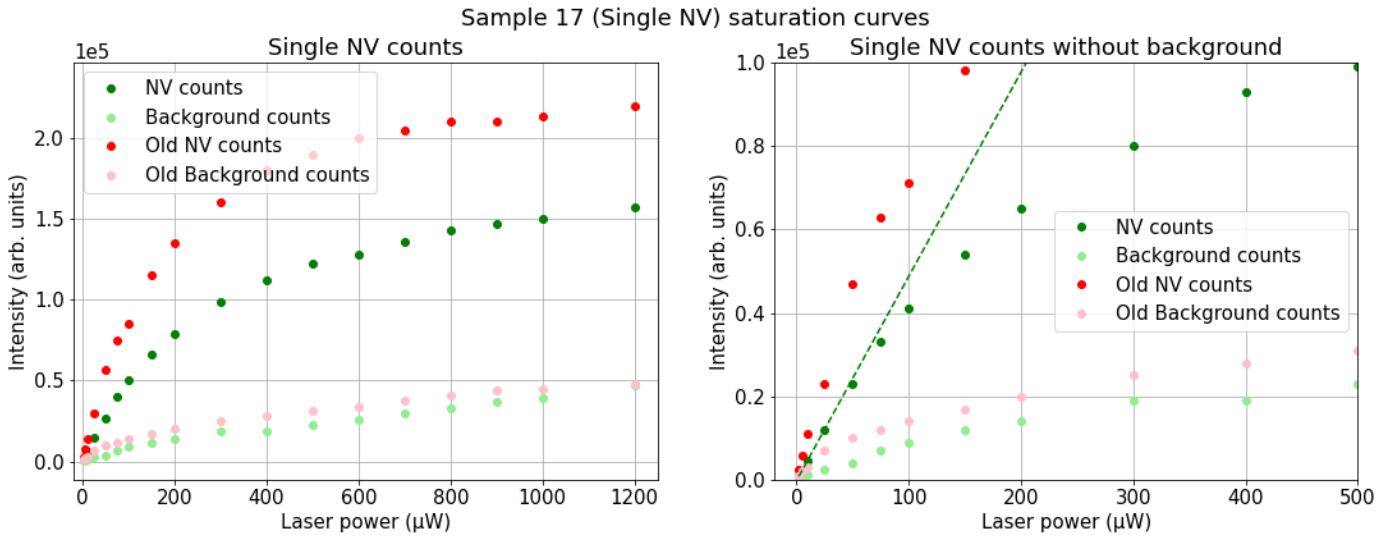
Name	**Instrument**	**Description**
NI Visa & NI MAX		Software for drivers for communication between PC and hardware of the setup.
Anaconda3		
Qudi		Open-source software written on Python. Config file “HZB_confocal-setup_default.cfg”.
PyCharm		To navigate and change qudi.
Notepad++		For quick access to scripts.
FreeFileSync		For backups.
IrfanView ImageJ Paint.net		Image editing.
TeamViewer AnyDesk		Remote control.
TopControl	CW laser	Software to control Toptica CW laser.
Kinesis	Thorlabs Mirror	Thorlabs software to control flipping mirror’s position.
TTi GPIB and drivers	MW source	For qudi MW experiments.
CONTROL	Pulsed laser	Control of the pulsed laser.
HASP	Spectrometer	For the USB-stick security key.
LightField	Spectrometer	Teledyne software for the spectrometer.
MCS6A	Counter	FASTComTech software for time-resolved measurements.
	AWG	TCP/IPv4 ip 192.168.1.3 of AWG. Set PC ip for the connection 192.168.1.3

Alignment

The CW laser beam height: ~12.5 cm. Thorlabs ruler BHM3 was used for the alignment; the beam maximum should be right in between two holes of the Thorlabs ruler (beam center is marked with "O" on the ruler). CW laser beam diameter ~ 1cm. **Check troubleshooting section if you suspect that alignment is off.**

The pulsed laser beam diameter is ~ 1 mm. Keplerian telescope system is used for the beam expansion. After the expansion the diameter is ~ 0.8 cm. Objectives input diameter is ~ 0.7 cm.

The setup was aligned using sample 17 (shallow NV centers, right after acid cleaning). NV counts 54000 at laser power P = 100 µW, background counts 9000.



Resolution and power density

Point separation:

$$r \approx 0.6\frac{\lambda_{laser}}{NA}$$

Air objective: 333 nm. Oil objective: 225 nm.

Source for more detailed calculations: https://www.olympus-lifescience.com/en/microscope-resource/primer/techniques/confocal/resolutionintro/

Some materials are sensitive to high laser power, and it can result in sample damaging. Compare laser power density acceptable for different materials.

$$I = \frac{P}{\pi r^2} = \frac{P}{\pi(0.6\frac{\lambda_{laser}}{NA})^2}$$

For example, for the air objective and the CW laser at power 100 µW the power density is I = 2.87e8 W/m^2.

MW power calculation

$$1\,V = \frac{(1\,V)^2}{50\,\Omega} = 0.02\,W = 10 * \log_{10}(0.02\,W * 1000) = 13\,dBm$$

$$-3\,dBm = \frac{10^{\frac{-3\,dBm}{10}}}{1000} = 0.0005\,W = \sqrt{0.0005\,W * 50} = 0.158\,V$$

To choose a correct amplifier and to calculate the delivered to the sample MW power, take into consideration maximum input and output of the amplifier, not only the gain.

Cleaning

All optical elements should always be handled with gloves!

Over time dust might collect on optical elements. For example, in case of the objective you might notice dark spots in the reflection of the sample on the screen before the detection part. These spots will not move when you move the objective around the sample surface. Use ethanol and isopropanol for cleaning.

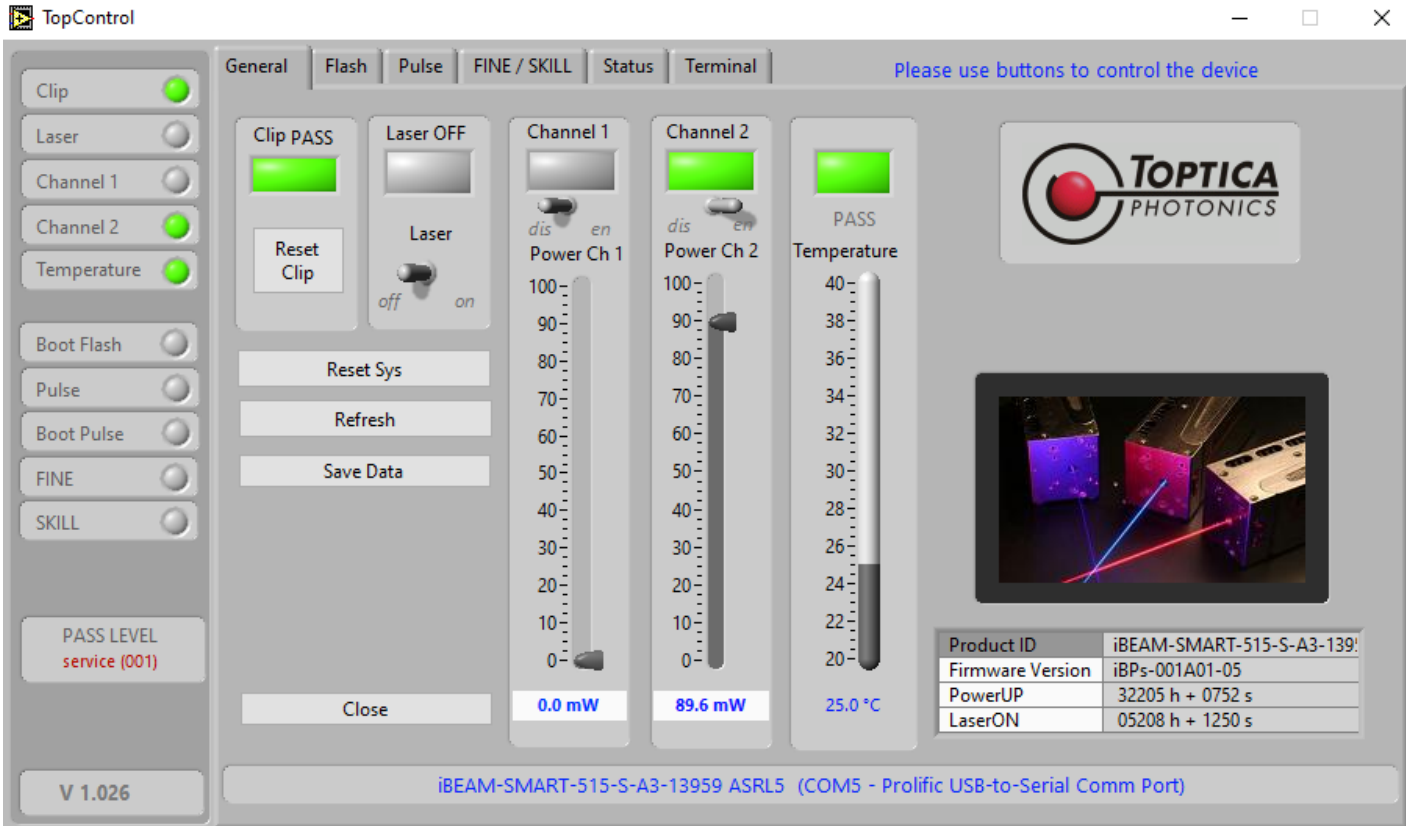
Acetone dissolves plastic, therefore, **do not use** it for cleaning unless instructed otherwise.

Operating

CW laser

Run TopControl software to control the laser. Channel 1 is responsible for CW mode, and we do not use it in our experiments. Channel 2 is responsible for the pulsed regime. Adjust laser power using neutral density filter in the setup since power control through the current adjustment in the software is non-linear. Typically for NV centers you start with 100 µW laser power, but for other samples you need to consider sample's sensitivity.

If sequence loaded to AWG is not "laser_on" laser **will not work**. Check Pulsed measurement section to upload proper sequence. After the upload press "Pulser ON" button and switch it back off to continue.



Pulsed laser

Put pulsed laser collimator in the holder and fix it. **Carefully** flip the flipping mirror to guide pulsed laser beam to sample. Flipping mirror is sensitive to movement so you might lose alignment if flip it roughly.

Use Control software to change pulsed laser's parameters. Turn on the laser, switch key to the 'on' position and press interlock button. Connect to the laser and change laser configuration. Typical parameters for an NV sample scanning: Wavelength 515-525 nm; Current 39%; Rep rate 78,2 MHz. Open "Laser aperture" valve and turn on the emission.

Align pinhole and detector positions. Do not change the alignment of the excitation part.

Switching of the objective

Block or turn off the laser. Remove the stage. Unscrew the objective and put it in the box. Place the desired objective on the stage. Air objective has an adapter ring. Never leave an objective uncovered. If you don't put a sample above it – cover it with paper to avoid dust collection.

Focusing

Start Qudi Confocal before focusing objective on the sample. Put X-axis, Y-axis and Z-axis sliders in the middle position (100 µ for X and Y, 0 for Z). Otherwise, the focused position will not be in the middle of the confocal picture. If you want to perform experiments with MW field, connect wires before focusing on the sample.

Some materials are sensitive to high laser power. To avoid photobleaching or damaging check laser power before starting the alignment.

3 screws are responsible for the Z position of the sample. Turn them clockwise to move away from the objective, turn them counterclockwise to move stage closer to the objective. Use leveler to correct tilts (use red marks on the leveler for correction). After focusing, remove the leveler from the stage.

2 screws with 10 µm step (full rotation = 500 µm) are responsible for X and Y position of the stage.

As the laser beam goes upwards always be careful during focusing, for safety reasons laser power should be kept below 1 mW during alignment! Adjust stage position so the sample is on the way of the laser beam. Approach the sample until you see a reflection on the screen. Use reflection to find the desired position on the sample. Approach the sample until reflection goes to the dot size and then overfocus it until the size of the reflection reaches approximately 5 mm diameter. Now you can start the scanning.

If you accidentally touched objective with the sample: do not move sample along X and Y axes to avoid scratching of the objective. Slowly remove sample away from the objective using Z-position screws. Clean objective and sample if necessary.

Glovebox

Always pay attention to the oxygen level inside the lab.

Use parafilm to isolate the objective tube. Place gloves in the glove holes and secure them using glove rings. There shouldn't be any wrinkles on the area where the gloves are fixed since it might create leakages. Turn on the power supply of the oxygen detector and pressure valve. Open the nitrogen supply valve. Open the window for the bleeding valve.

Open oxygen sensor valve **at least after 60 minutes of > 10 LPM pumping**. A high level of oxygen inside the glovebox can cause inaccuracies in the sensor and damage it. % on the left upper corner of the oxygen sensor screen means that the sensor went from ppm level measurement to percentage.

Pressure increasement inside the glovebox moves the objective isolation creating fluctuations (the higher the pressure, the further from the focus the objective is, with the pressure valve opening it returns to the focus). The bleeding valve stabilizes the pressure.

The glovebox under fully open valve pumping can reach below 10 ppm level. However, bleeding valve cannot compensate this pumping level, so it will trigger the pressure valve. The minimum reachable oxygen level with stabilized pressure is 13-15 ppm. The pumping should be above 10 LPM but not fully open to reach this stabilization.

Before using the gloves to work inside the glovebox, remove jewelry and watches from your hands since they can break gloves. Put on cotton gloves. Get inside and outside of the glovebox's gloves slowly.

Magnetic field

Do not place objects sensitive to the magnetic fields close to the magnet!

If you need to remove magnetic field but don't want to change the alignment: unscrew the stage with the magnet, not the whole structure. **Attention**: there are small parts holding the stage, be careful not to lose them!

Software

Qudi

Qudi is a python-based software that we use for our setup. You can read about it here.

C:\qudi\config\qo-config\setup12 path has the configuration file and pulsed fitting methods.

“setup12_default.cfg” configuration file is used for the confocal setup. The configuration file includes information about all connections of hardware and is used for communication between Qudi software and setup’s hardware. All connections and configurations provided in this document are actual only for the confocal setup!

When you want to specify data name in qudi GUI **do not to use forbidden symbols in filenames** as it can’t be saved, and your data will be lost.

Counter

Always start the counter before turning on the APD.

At high count rate APD works nonlinearly. In current configuration it starts at 1000 kc/s. Multiply measured counts by a correction factor from the APD’s table to get a real count rate if the count rate is higher than 1000 kc/s or adjust excitation power to keep count rate lower.

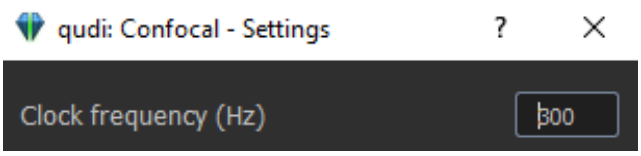
Keep the count rate **below 30000 kc/s** to avoid damaging of the APD.

Confocal

Start confocal before focusing objective on the sample. Put X-axis, Y-axis and Z-axis sliders in the middle position (100 µ for X and Y, 0 for Z).

Resolution: how many points you want to have for each axis. Making steps smaller than resolution limit will cause oversampling – neighboring pixels would capture the same information.

Options > Settings > Clock frequency: determines how fast each pixel will be scanned. For photobleaching of the sample can be decreased. Change the clock frequency back after photobleaching.

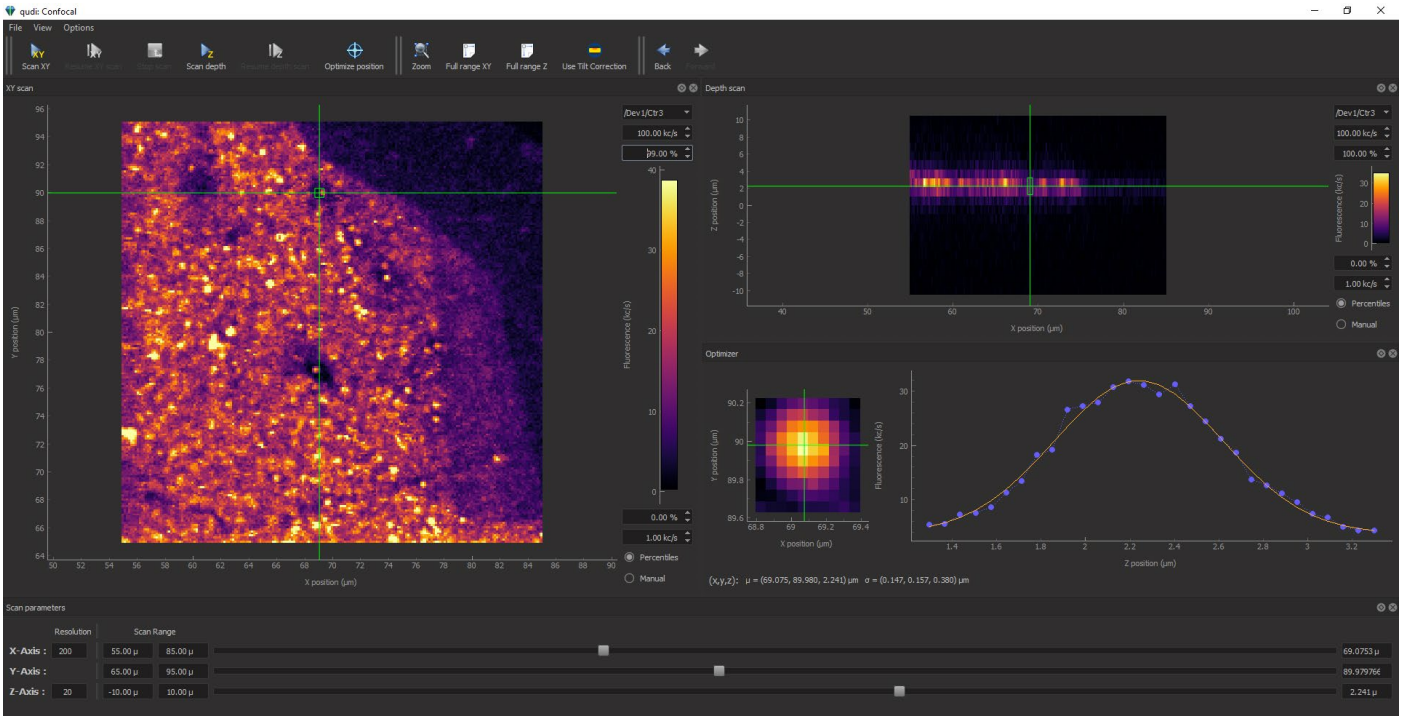


Scan depth to find the surface of your sample. Correct Z position by moving the green cross and putting it on the PL level. Nominal scan range is from -10 to 10 µm. You can scan smaller areas by changing the Scan Range.

Scan XY. Move the green cross to the desired point to focus on it. Optimize position until maximum count rate is reached. Nominal scan range is from 0 to 200 µm. You can scan smaller areas by changing Scan Range.

Change contrast of the picture by changing percentage of the Fluorescence scale.

If you need to change the scanning area, be aware that confocal image is mirrored. **Rotate left screw to change X-position: clockwise (towards yourself) to move confocal frame to the left, counterclockwise (away from yourself) – to the right. Rotate bottom screw to change Y-position: clockwise to move confocal frame upwards, counterclockwise – to move it downwards.**



Cwawgswitchgui

You don’t need to use it if for pulsed experiments external MW source is connected (check Switcher section).

For ODMR experiments put slider in “CW Microwave” position. For Pulsed measurements put it in “AWG” position.

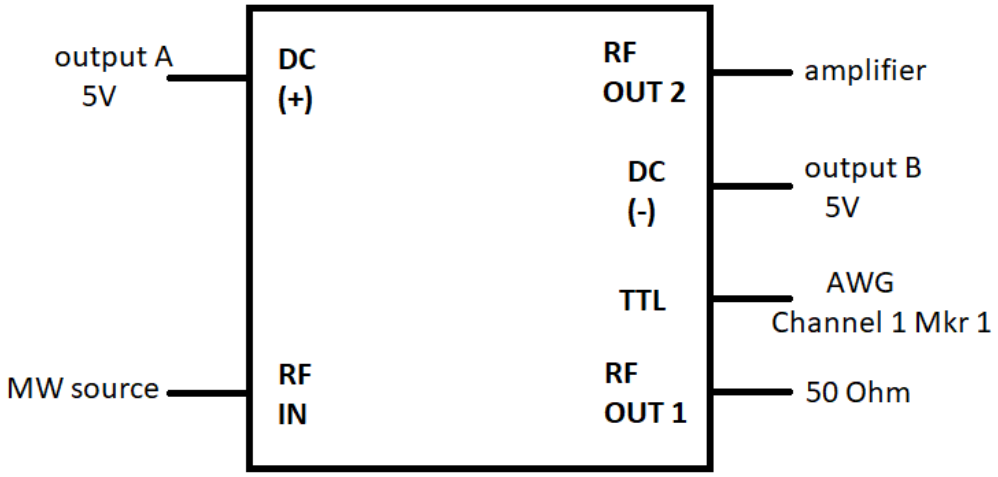
Switcher always starts at “CW Microwave” position even if it was left at AWG position before quitting Qudi! Move slider to “AWG” and back to correct this.

Switcher

Depending on the pulse sequence for pulsed measurements and required sequence length there are 2 types of switcher connections:

External MW source

AWG channel connection depends on the chosen channel in qudi Pulsed measurements software. Choose d_ch1 in pictured configuration or change accordingly.

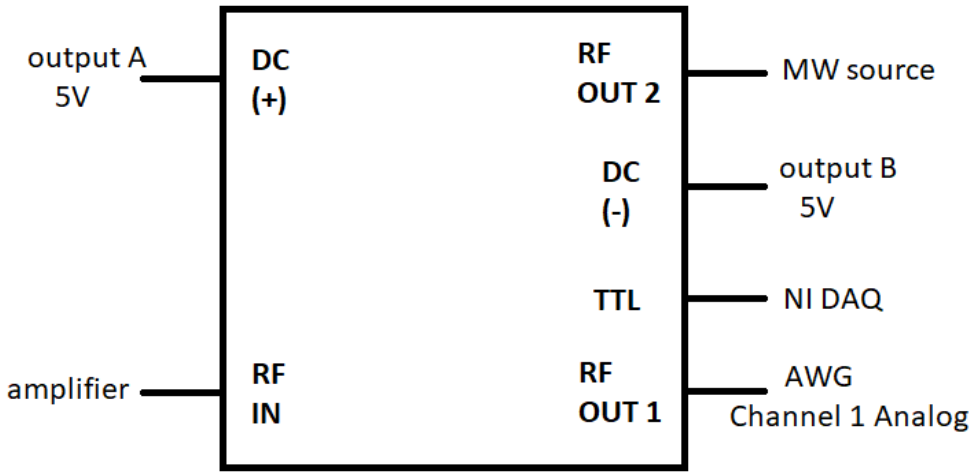


AWG as a MW source

AWG channel connection depends on the chosen channel in qudi Pulsed measurements software. Choose a_ch1 in pictured configuration or change accordingly.

For TTL NI DAQ PFI 7\P1.7 output is used.

+7 dBm of the external MW source is roughly equal to 1 V of the AWG.



ODMR

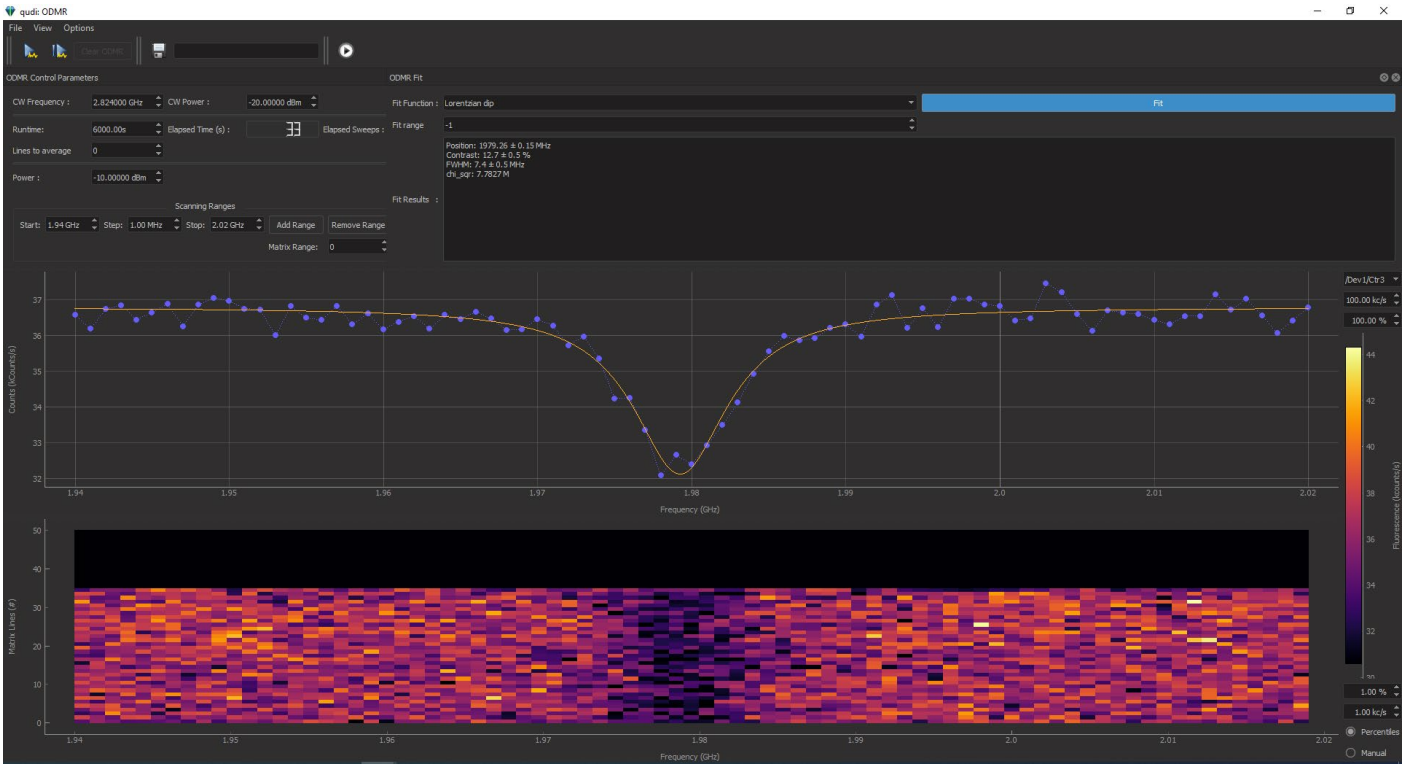
Switch on the MW source before opening the ODMR window!

Turn on the MW amplifier before starting the experiment. **Switcher always shows "CW Microwave" position at the start even if it was left at AWG position!** Move slider to "AWG" and back to correct this.

If the count rate reduces over a time – you observe heating effects. Reduce MW power.

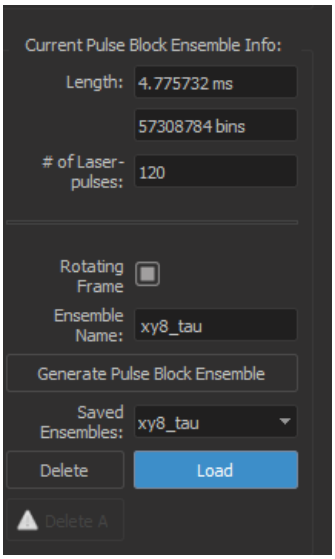
ODMR doesn't save fitting data, so write it down if you need it.

If you change amplifiers for measurements, pay attention to gain and maximum input power of the amplifier. If you observe widening of the ODMR peaks – reduce the input power.

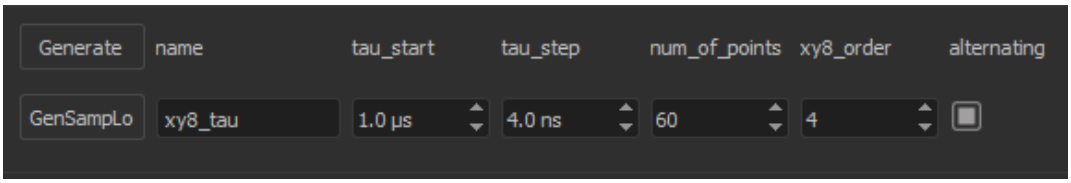


Pulsedmeasurement

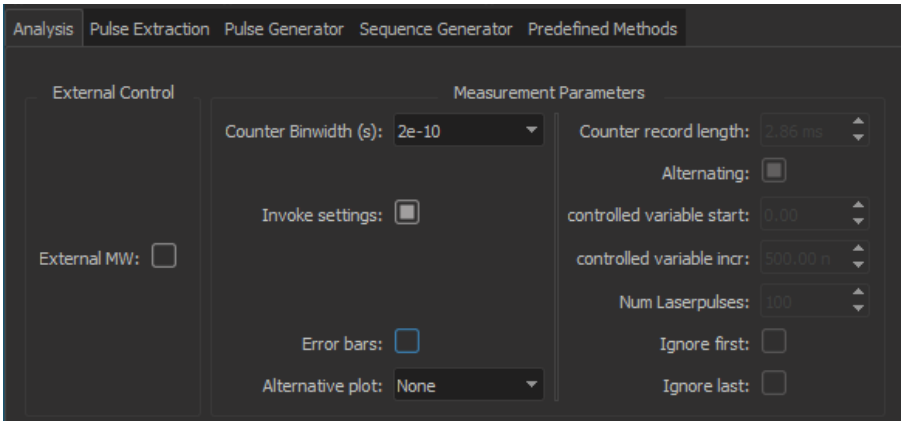
Run the counter software MCS6A(x64) and turn on the MW source before opening the Pulsed measurement window!



AWG has a total memory of 64.8 Mb for each channel. Error will occur only if you try to download sequence longer than that, but not if the downloaded sequence is bigger than the left space. To check the size of the sequence you need to generate it without downloading by pressing “Generate” button. Then check its’ size in the tab “Pulse Generator”. To do this choose your sequence at “Saved Ensembles” and press “Load” button. The number of beans shows the size of the sequence and should be smaller than 64800000 or less if there are other ensembles already downloaded to the AWG. Play with parameters or adjust Sampling Frequency in settings. Be careful with the latter since too small sampling frequency will not create desired pulse shapes.



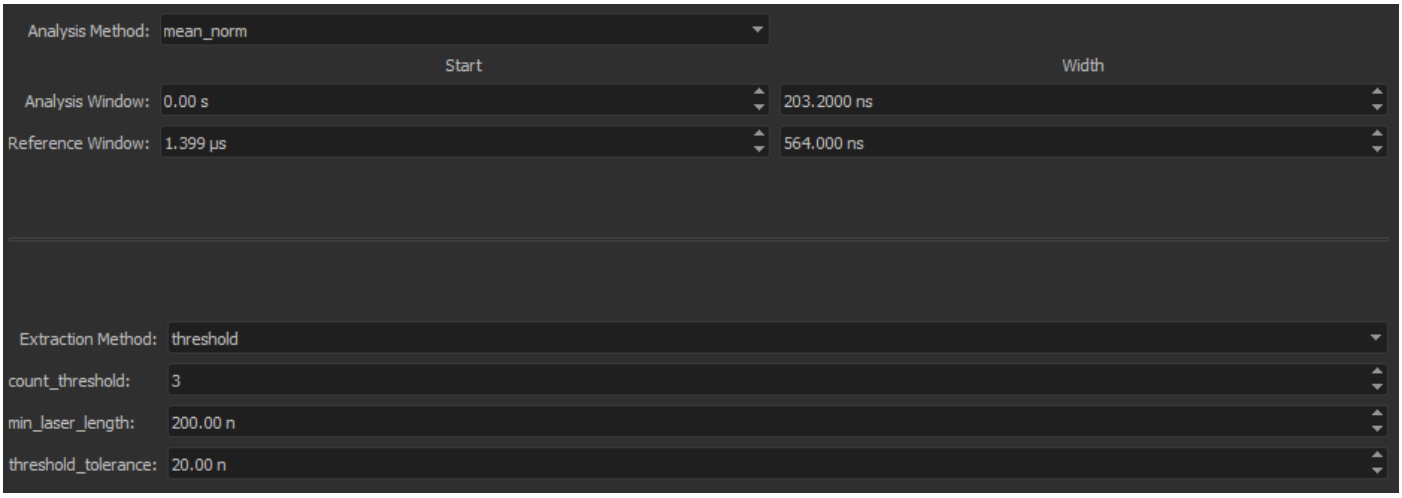
Before starting a new measurement check whether the Invoke settings square is ticked. **It should always be ticked for sequencies from Predefined Methods.** Otherwise, the counter’s parameters will not be adjusted for running measurement and results will be wrong.



If you change the amplifier for measurements, reduce microwave_amplitude accordingly to avoid artefacts.

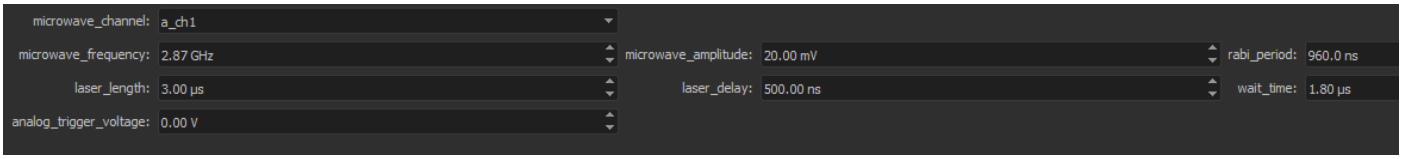
Pulse extraction parameters can help with increasing contrast and reducing noise level. Find optimal analysis and reference windows for your signal, for example, by observing the Rabi contrast.

Adjust count_threshold value to approximately middle of the counts level in the MCS6A counter software to reduce noise.



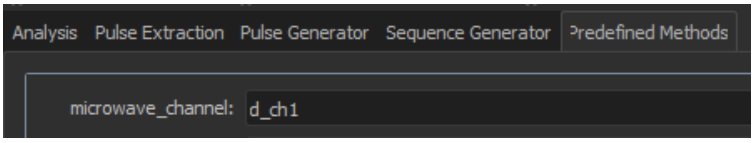
Pulsed ODMR

For the pulsed ODMR measurements the Rabi frequency should be significantly low so it would not excite energy levels splitted due to hyperfine interactions. Reduce microwave amplitude so that the Rabi period is equal to roughly 1 µs. Reducing the power will also cause the Rabi contrast decreasement.



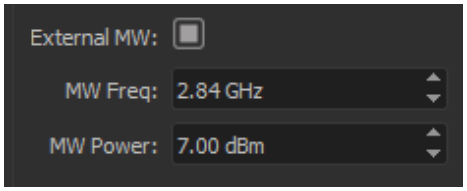
External MW source

Some sequences might be too heavy for AWG. If you don't need different phases of MW signal (such as at XY8 sequence), you can switch setup configuration from AWG connection to the external MW source (check Switcher section).



Change the microwave_channel from a_ch1 to d_ch1.

In the "Analysis" tab change microwave_frequency value to the resonant frequency from ODMR measurements (MW Freq value for the external MW source).



Use microwave_amplitude value 1 V (MW Power 7 dBm for the external MW source).

Jupyter notebook

Run Anaconda Command Prompt. Jupyter notebooks scripts are located at C:\Data\Scripts. Write "**conda activate qudi**". Run jupyter notebook.

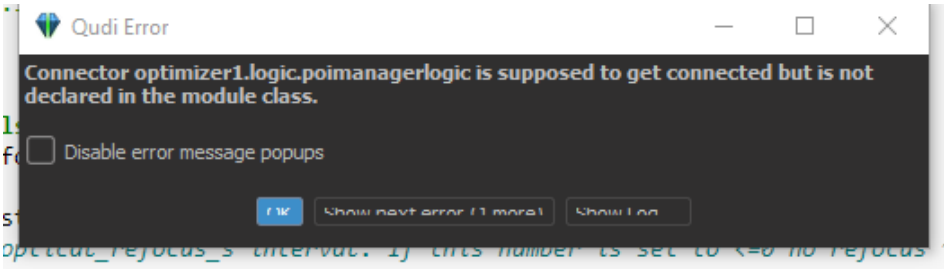
NV refocusing

For long pulsed measurements it is required to refocus on the NV every ~20 min. There is a python script for this: "NV refocus.ipynb".

Depending on pulsed sequence you need to change "running_pulse_seq_name".

```
In [4]: import multiprocessing
        exec(open(r'C:\\Data\\Scripts\\notebook_methods.py').read()) #path to notebook script
        refocusing_time=1200     # Time to refocus in seconds
        measurement_time=200000  # Measurement time in seconds
        running_pulse_seq_name='xy8_tau'#'hahn_echo'
```

Run first cell. After a successful connection this error will occur:

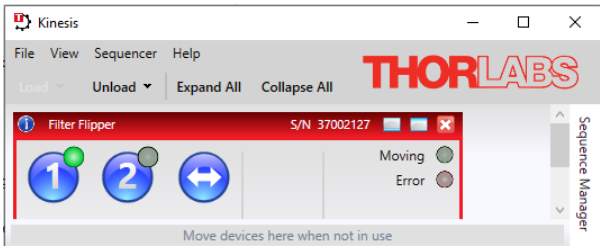


Start pulsed measurements and run other cells. Script will stop automatically when you stop pulsed measurements.

LightField Spectrometer

Flipping mirror

Run Kinesis software to flip the mirror to guide fluorescence towards spectrometer. *Position 1*: beam is guided towards the APD. *Position 2*: beam is guided towards the spectrometer.

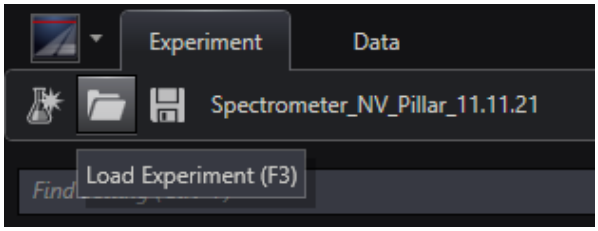


LightField

To check spectrum of the sample run LightField software.

Load the desired experiment.

Open “View” tab to open a spectrum window.

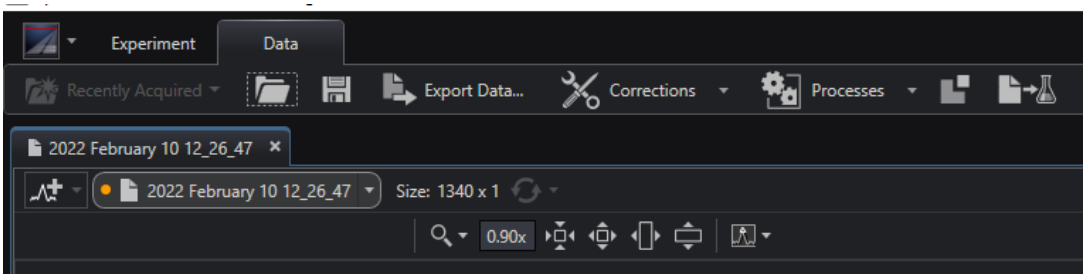


Keep intensity (counts) of the spectrometer below 60000 to avoid saturation of the sensor. Before starting measurements wait until sensor’s temperature reaches the setpoint -50°C.

Take one frame: to check spectrum without saving it.

Run: to continuously make frames without saving them. Usually used for alignment with full sensor RoI (region of interest). Press Stop to stop it.

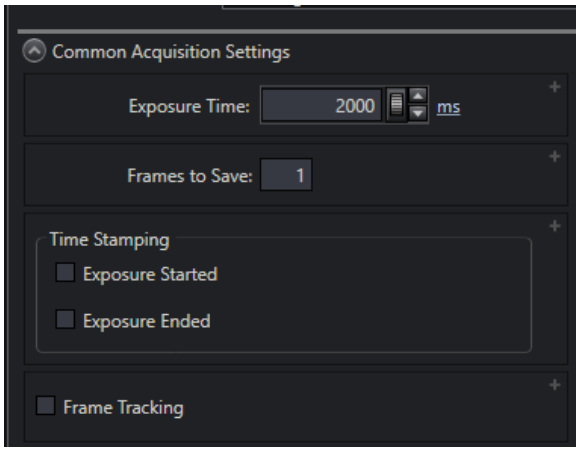
Acquire: to measure spectrum and save it. File will be saved with current date and time in the folder from the “save data file” setting.



Open Data tab to check, correct, compare and save acquired spectra. Use “Export data…” to save it in .csv format.

Common Acquisition Settings

To get better spectrum shape with less noise, increase the exposure time. Decrease it if you reach saturation. Change the number of frames to save several spectra in one file (for example, to record changes of spectra over long laser exposure).

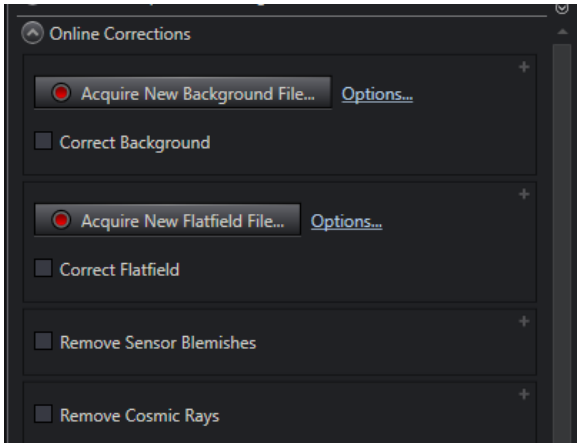


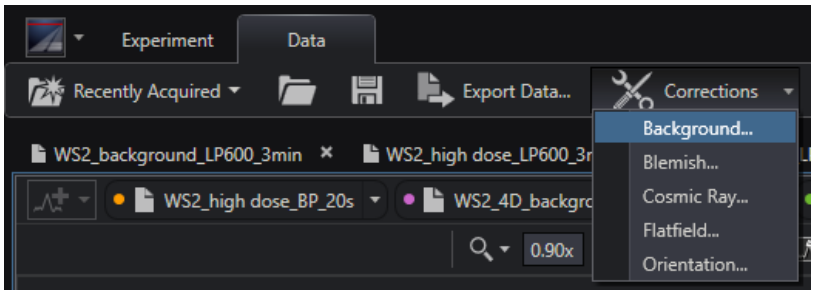
Online corrections

Measure Background spectrum without incoming fluorescence to set spectrum to zero and remove thermal noise.

Overtime spectrum baseline might shift due to noise. It might be disturbing for data comparison. Do not use background correction under those circumstances or use corrections before saving spectrum in the Data tab. In the latter case save a background spectrum with the same parameters as a sample spectrum and then subtract it manually.

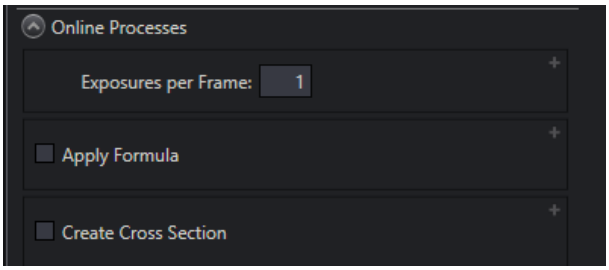
For long exposure times you can remove cosmic rays. You can also do it after measurement using corrections tools. **Cosmic rays' correction will affect all points of your spectrum!** It might be better to remove them manually during the analysis.





Online processes

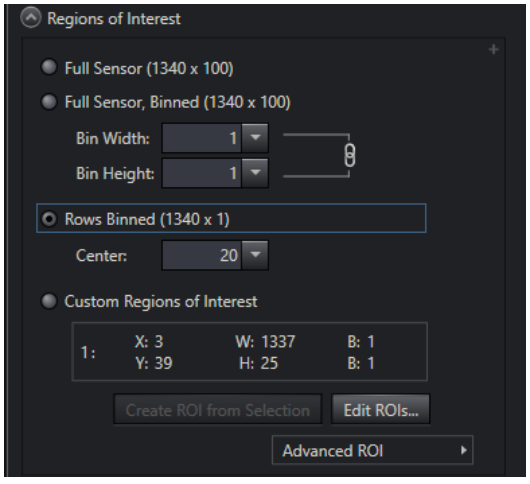
If you saturate sensor but need to measure spectrum with certain exposure time you can try next: reduce twice the exposure time but make 2 exposures per frame. It will sum up two frames and give you roughly the same results. Disadvantage: final noise will be higher as it will not be reduced but summed up.



Regions of Interest

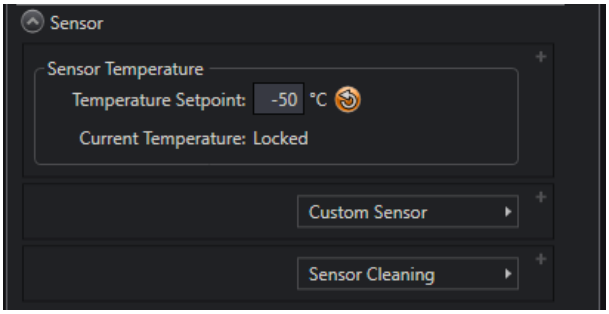
Use *Full Sensor* for alignment and to check width of the enlightened area.

For spectrum measurements use *Rows Binned* with number of rows defined from the full sensor.



Sensor

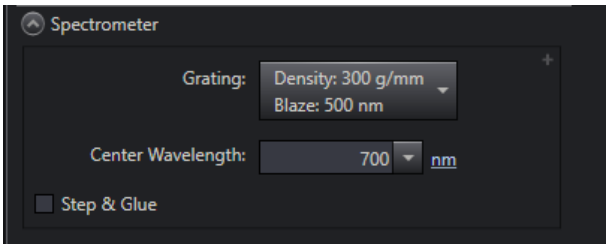
The sensor can't be cooled down lower than -50 degrees even though the default value is -75°C.



Spectrometer

Normally grating should be with blaze (central wavelength) 500 nm. For UV light use grating with blaze 1000 nm (in LightField it shows 100 nm, but actually it is 1000 nm).

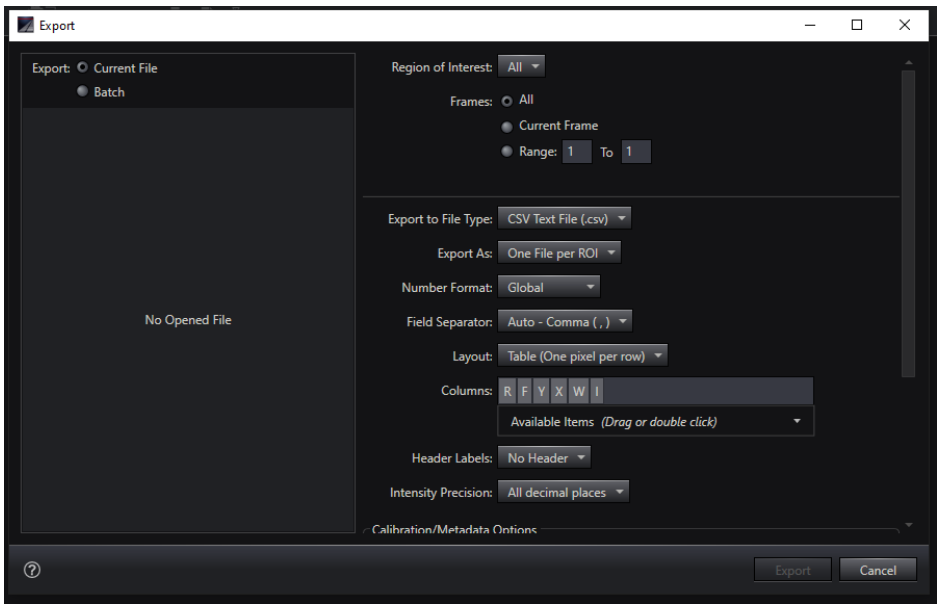
Adjust Center wavelength to put peak of the spectrum in the middle.



Saving data

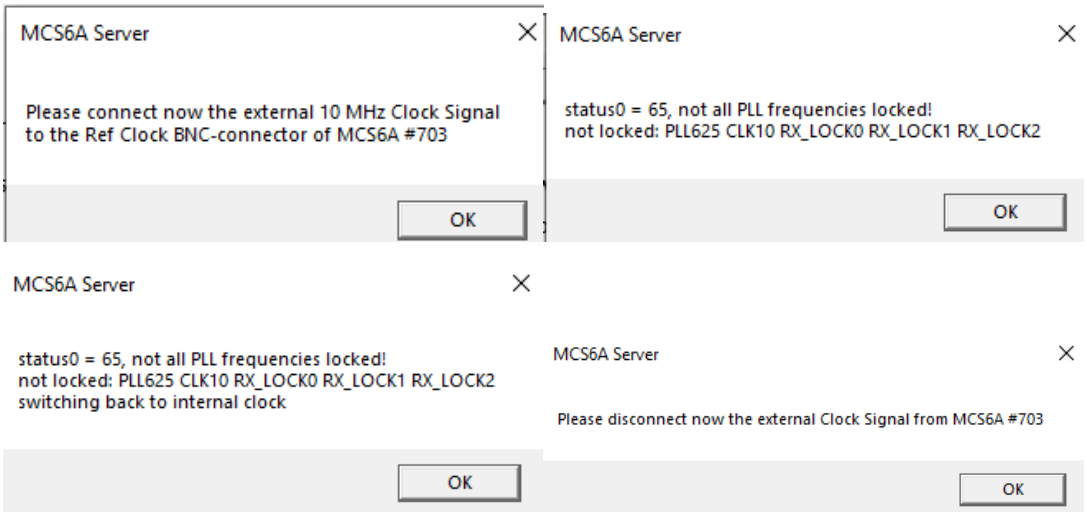
When you save the spectrum, it is saved in a .spe format. To save data in a different format, use "Export Data…" button. Here you can change the export file type. By default, we use .csv format and files are exported to the same folder, where the spectrum was saved.

Make sure that in Columns you have W for wavelength and I for intensity. If you take several spectra in one go, make sure that you have F for frames.

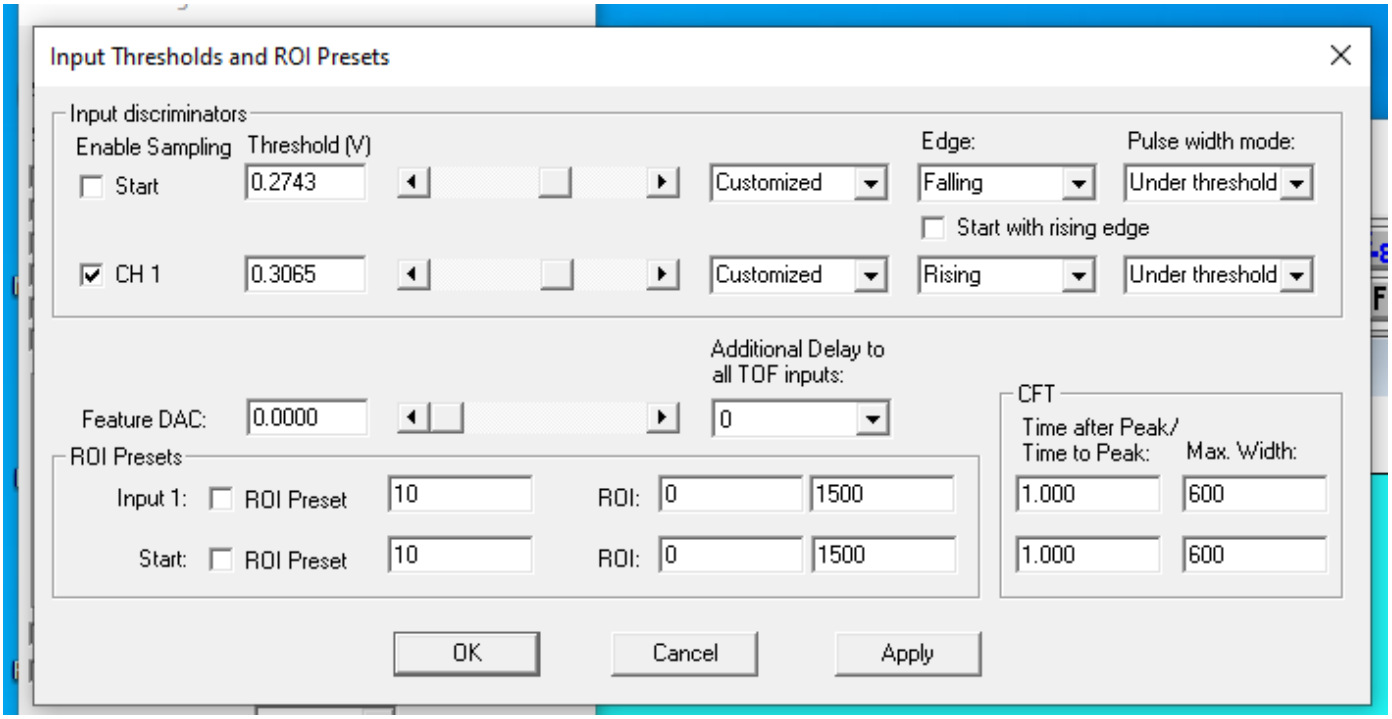


MCS6A Counter

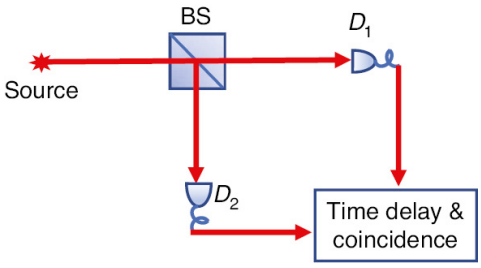
If you don't have external Ref Clock source next errors will appear. You can ignore them.



Counter hardware settings. **Do not change!**



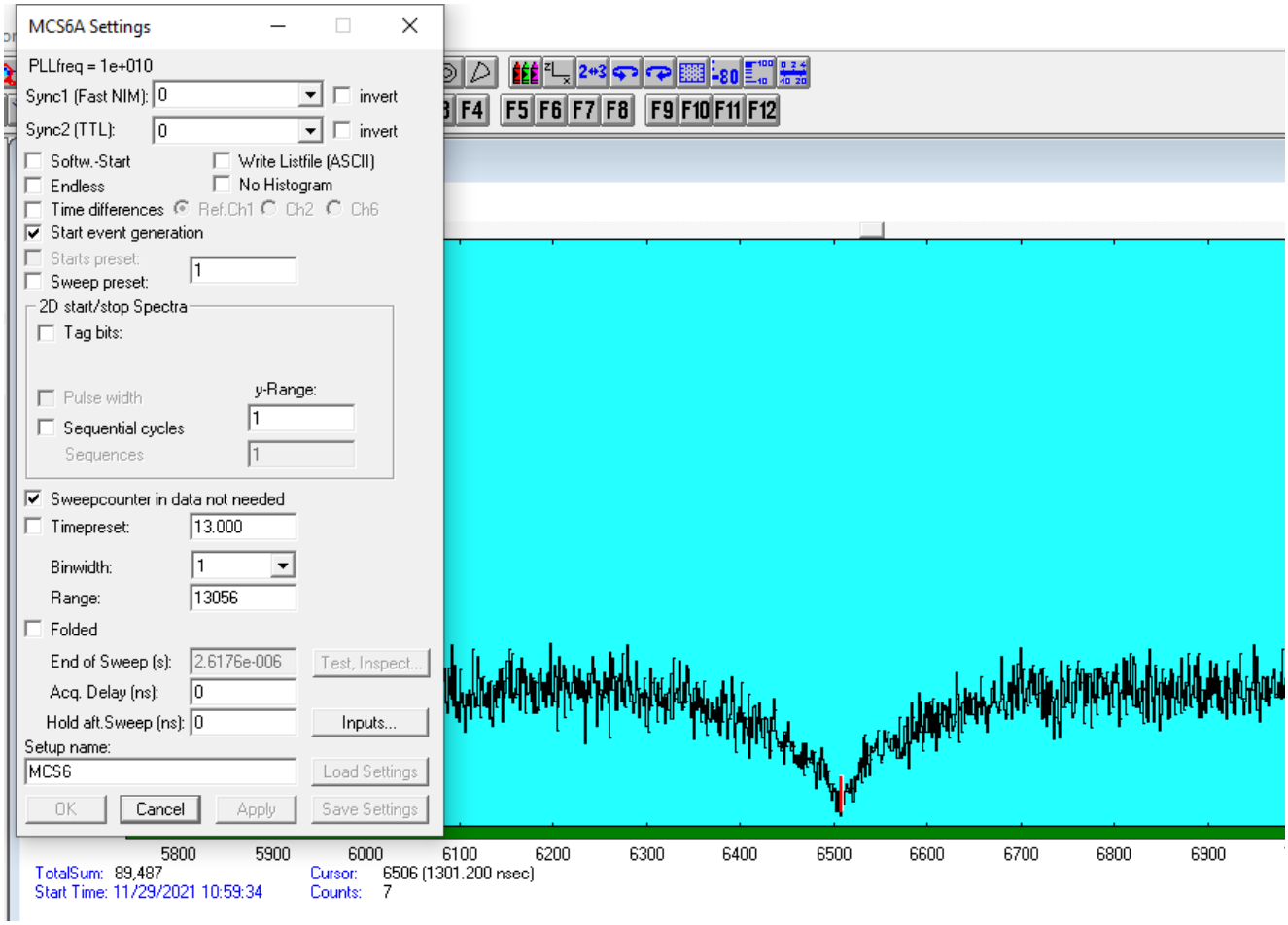
Antibunching



Use Hanbury Brown and Twiss connection: place a 50:50 beam splitter and align the second APD.

To perform antibunching measurements connect second APD's output to the "START" of the counter and copy of the first APD's signal to the "STOP1". **Use attenuation if voltage of the signals is not in the range from -2 V to +3 V.**

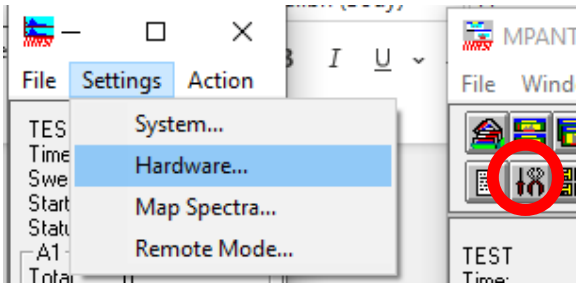
In settings check whether your range is too high. Copy of the first APD's signal is delayed so the dip is located at 6500 (1300 ns) for the current configuration. Use Range twice higher so your dip will be in the middle of the picture.



Lifetime

Align pulsed laser for lifetime measurements. Connect “Pulse monitor” output of the SuperK pulsed laser to the “Start” of the counter.

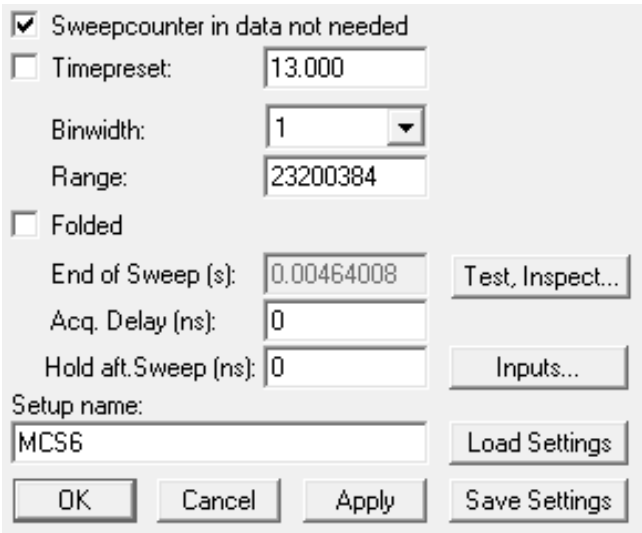
For the pulsed laser the average count rate is shown in qudi counter, so real counts can be higher during laser pulses. To avoid artefacts coming from the copied signal from the pulse generator, reduce the laser power via neutral density filters.



Go to Settings > Hardware or press tool button. Change Range according to the required time scale. **Range 1 equals 1 bin which is 100 ps**. You can start with range 2000.

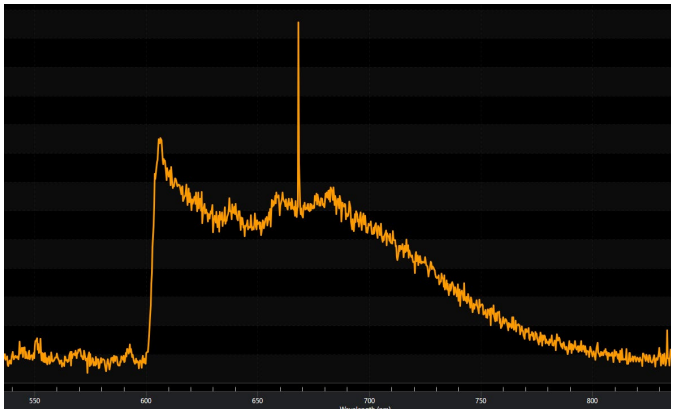
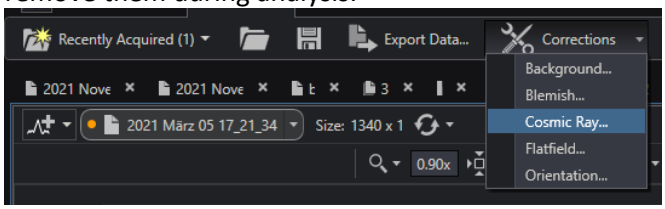
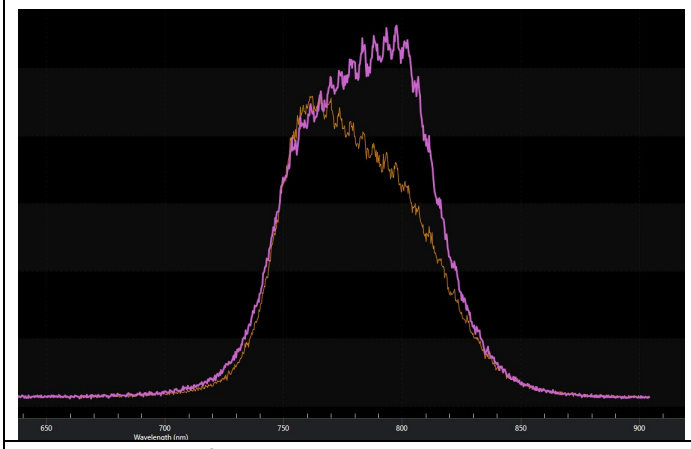
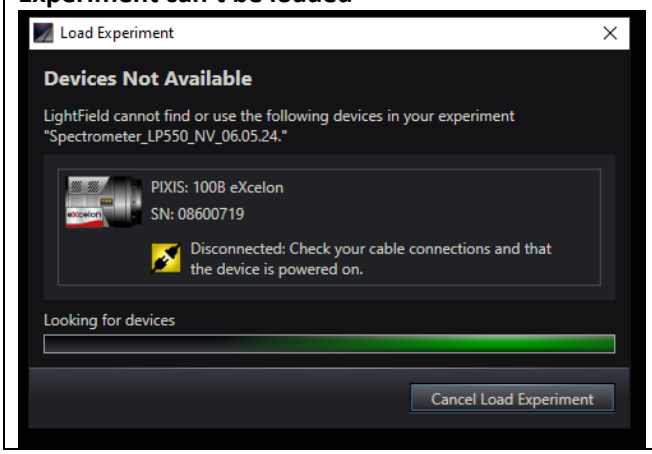
Change Acq. Delay to shift lifetime peak to compensate delays from the setup if needed.

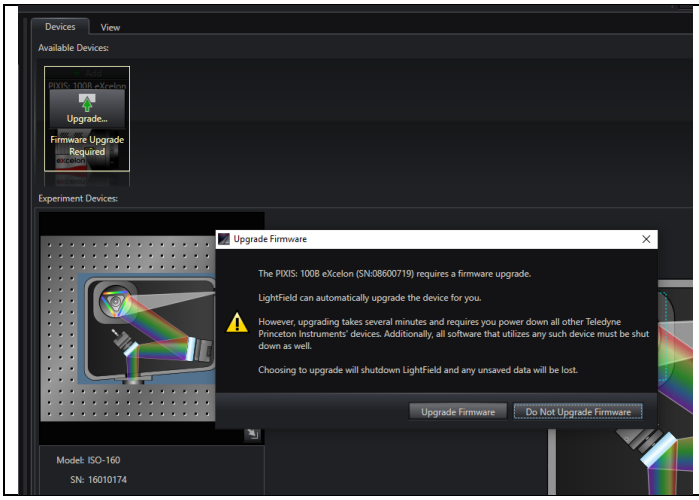
Reduce the repetition rate of the pulsed laser to 2.89 MHz, increase the current so the count rate is high enough for the detection and then start the measurement.



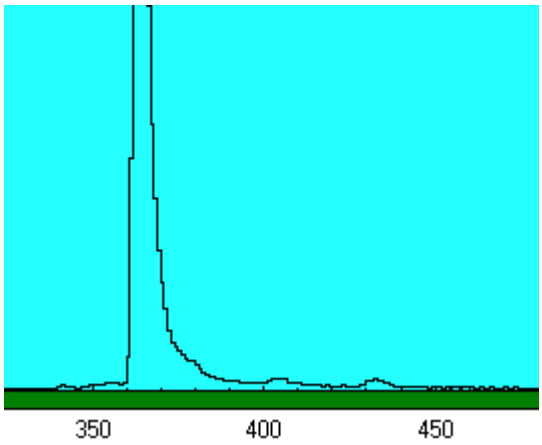
Troubleshooting

Spectrometer

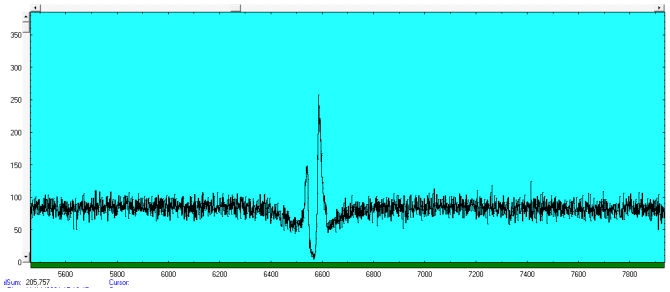
Sensor temperature is not stable.	Set Temperature Setpoint to -50°. Reason: Sensor can't cool down below -50°.
Sensor from locked state starts heating up or does not cool down.	A solution hasn't been found yet. The spectrometer has a liquid cooling system and requires additional equipment to reach low temperatures.
Unexpected sharp peaks at the spectrum.  	Try cosmic ray correction, remeasure the spectrum or remove them during analysis.  Reason: detection of high energy particles coming from space.
Waves on the high wavelength spectrum.  	Can't be fixed? Reason: might be that an optical interference happens somewhere in between objective and spectrometer. At higher wavelength optical interference effects are more pronounced. Another potential reason might be that at higher signal intensities the CCD enters a non-linear response region. The CCD also has lower quantum efficiency in IR region and more susceptible to electronic noise.
Experiment can't be loaded  	Try to turn off the power and then turn it on. Reason: was observed when there was a problem with USB connectors.

Lifetime

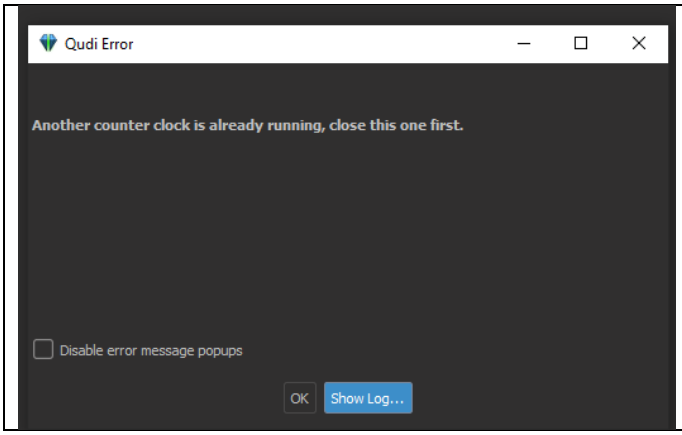
Many peaks on the exponential decay. 	Reduce laser power. Reason: the signal generator creates artefacts when the count rate is too high.

Antibunching

Additional peaks around dip during CW antibunching measurements & a triple-peak during pulsed AB. 	Add SP750 between an APD and a beam-splitter. Reason: afterglow effect of the APDs.

Counter

Counter shows an error that it is already used in the other software. **NI pop-up window with a new device.**	Restart NI DAQ and qudi. Reason: it might happen that NI DAQ has some internal error that is not shown, restarting it should help.

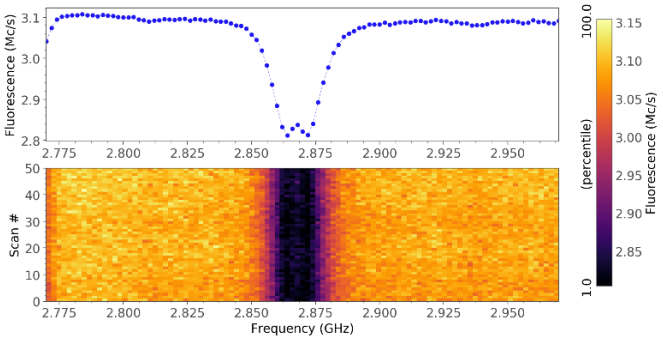
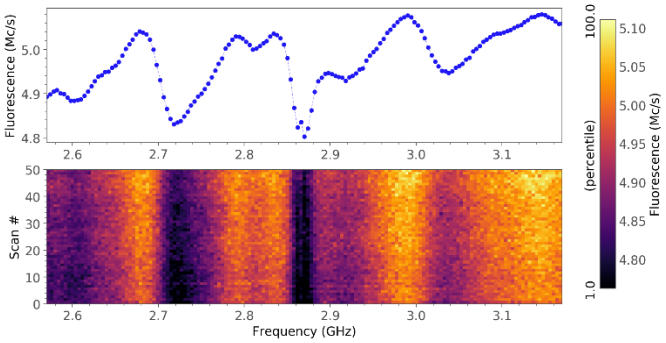
	

Confocal

Counts from the qudi counter and confocal image do not match each other.	Restart NI DAQ. Reason: it might happen that NI DAQ has some internal error that is not shown, restarting it should help.
Photobleaching of NVs.	Screw properly stage screws. Reason: there are tiny movement of the stage that disturbs focusing on an NV center. Otherwise, it might be a sample problem.
Objective doesn't move during the scan.	Check whether piezo stage is off. Turn it on as well as feedback on the front panel. Otherwise, it's possible that your sample is touching the objective. Move the sample stage away from the objective.

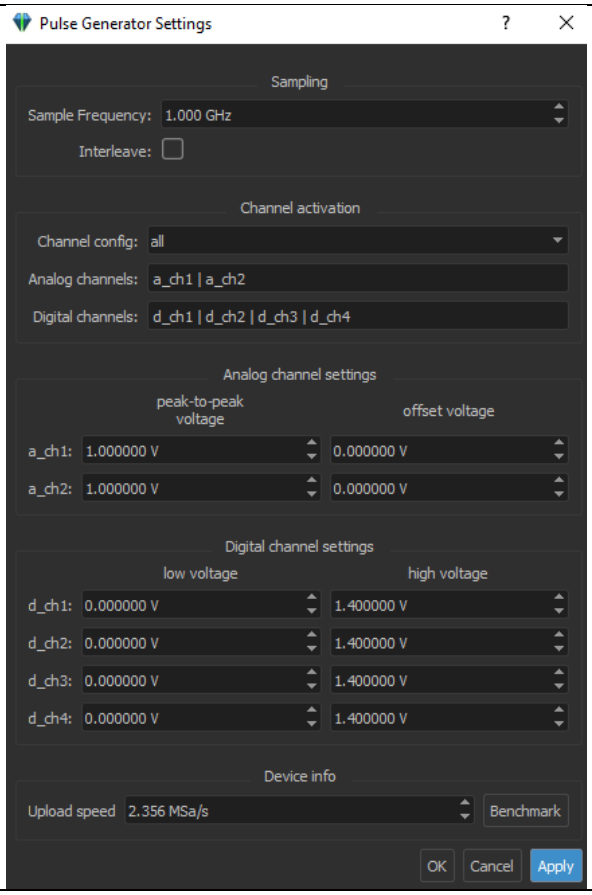
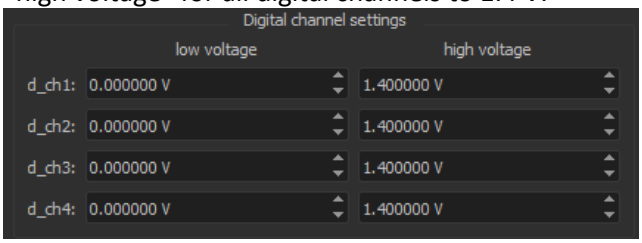
ODMR

Count rate gets lower over time.	Reduce power. Reason: heating effects or movement of the sample holder.
Error at the start, timeout error.	If "Remote" and "On" red lights are on – you need to restart the MW source. Reason: the MW source is running and qudi can't connect to it due to yet unknown error.
Sudden ODMR contrast loss.	If there are no changes in the background PL, turn off the amplifier's power supply. Check whether it is set properly (4 A, 28 V), check cables connection. Reason: amplifier doesn't work properly.

Resonances on the left edge in sweep mode. 	Change CW mode frequency. Reason: At the end of the sweep mode MW source TTi returns to the CW frequency before starting a new sweep.
ODMR waves. 	Do not use double-tape for experiments with a MW field, glue your sample to the holder. Reason: mechanical oscillations of the double tape.

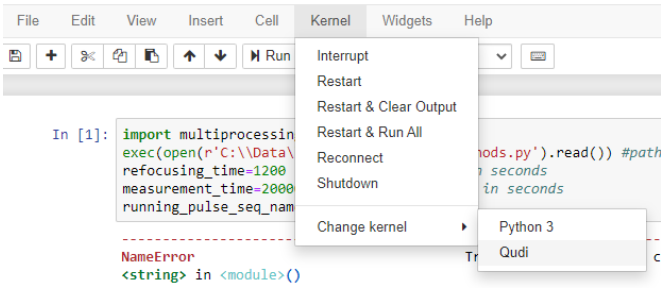
Pulsed measurements

AWG is overloaded. **OR sequence/pulser was started before download was complete.** **OR "Pulsed measurements" shows errors on the start.** **OR sequence loading takes forever.**	Restart AWG software using its' sensor screen or connect mouse to it, wait until the full check. Restart qudi, check voltage in settings and correct if required. Reason: there were already sequencies downloaded and sum of their length was higher than 64,8 Mb. OR there was an error during 'talking' of the PC and the AWG.
Sudden Rabi frequency increase.	If there are no changes in the background PL, turn off the amplifier's power supply. Check whether it is set properly (4 A, 28 V), check cables connection. Reason: amplifier doesn't work properly.
Pulse Block Editor doesn't load blocks.	Open Settings > Pulse Generator Settings > Apply (Sample Frequency and Upload speed might be different!)

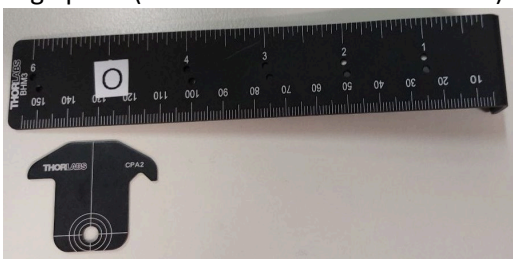
	
First points of the data are wrong.	Change the value of tau_start from 0 to 10 ns / 50 ns / 1 µs depending on the pulse sequence. Reason: pulses are coming too close to each other, and first points read-out are overlapping. In XY8 measurements starting from 0 causes shift of the detected signal.
There is no laser emission.	Open Settings > Pulse Generator Settings > Change “high voltage” for all digital channels to 1.4 V.  Reason: after some errors high voltage parameters might reset. AWG requires voltage 1.4 to work.
Counter range is incorrect.	Check “invoke settings”. OR Close the Pulsed measurements window, restart the software and reload the pulsed measurement in qudi. Reason: if the software was used for different measurement (antibunching, for example) and wasn’t reloaded it can’t adjust to pulsed measurement settings.
Complete loss of focus during measurements.	Reduce microwave amplitude. Reason: a movement of the sample holder was observed with the max amplitude and the RF amplifier.

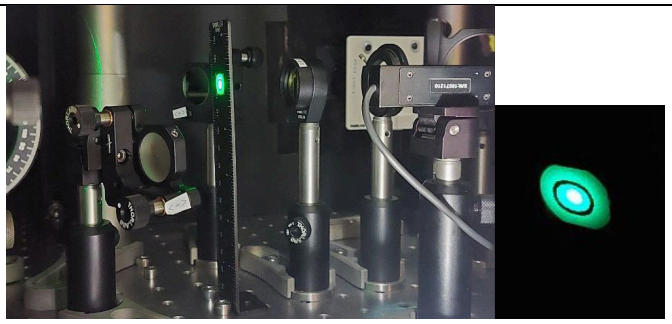
Qudi warning in log: The counter receives only zeros. No counts in the MCS6A software.	Check parameters of the START and STOP signals, check AWG voltage and channels. If everything is correct, exit the software and turn off the counter by unplugging it from the electricity. Plug it back and run the software. Reason: the fast counter doesn't receive one of the signals.

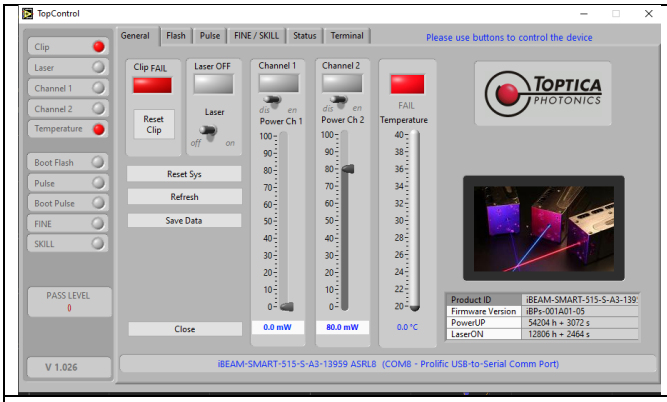
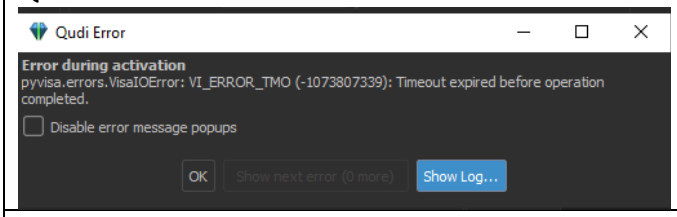
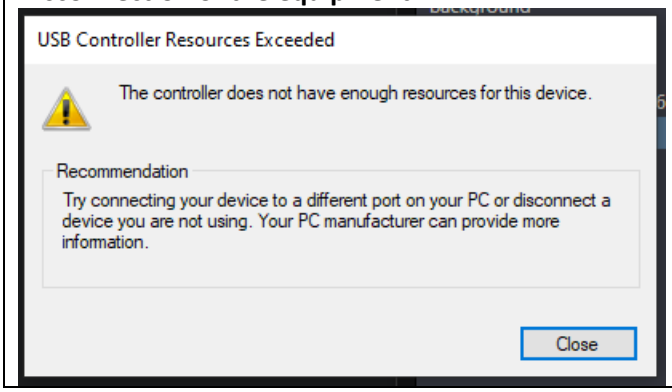
Jupyter notebook

NameErrors in a script that worked before.
 	
`NameError Traceback (most recent call last)`
`<string> in <module>()`
 	
`NameError: name 'pulsedmasterlogic' is not defined`
 	
`During handling of the above exception, another exception occurred:`
 	
`NameError Traceback (most recent call last)`
`<ipython-input-1-34cdab6024ce> in <module>()`
`1 import multiprocessing`
`----> 2 exec(open(r'C:\\Data\\Scripts\\notebook_methods.py').read()) #path to notebook script`
`3 refocusing_time=1200 # Time to refocus in seconds`
`4 measurement_time=200000 # Measurement time in seconds`
`5 running_pulse_seq_name='hahn_echo'`
 	
`<string> in <module>()`
 	
`NameError: name 'manager' is not defined`
	Change kernel to Qudi or, if it's not there, install it using [this instruction.]
	
	 
	
	Reason: Qudi's jupyter notebook scripts require Qudi kernel.

Hardware

Alignment is off.	Use the ruler for the excitation part and the aim for the cage parts (both excitation and detection).  <u>Excitation part:</u> To confirm that alignment is wrong, unscrew the objective and check the beam position. There is a mark on the ceiling of the glovebox, if the beam is away from this mark – the excitation part needs realignment.  Use the ruler to check the laser path. Center of the beam should be in the center of the "O" label.

	 Hang aim on rails of the cage system and check that the beam maximum is in the middle of it. <u>Detection part:</u> First, check if there is light coming out of the pinhole. Move the lens in front of the pinhole in Z direction and the pinhole in X and Y directions until the passing through the pinhole emission is the most intense. Remove the filter in front of the APD and ensure that the laser spot is visible on the APD shutter. Use a sample with bright fluorescence to adjust the pinhole and APD position, maximize APD counts. Use a sample with single NVs to make final adjustments. <u>Spectrometer:</u> Remove the filter and make sure that the laser spot passes through the spectrometer's slit. Change "Region of interest" to full sensor. Reduce exposure time to 1 second. Run the spectrometer detection in continuous mode and adjust the laser path to maximize the detection.
Laser doesn't work.	If: • you downloaded sequence to AWG is "laser_on" • you've tried running the sequence ("Pulser ON" button) • in "Pulsed measurements" settings digital channels high voltage is 1.4 V for all channels • in TopControl channel 1 works, but channel 2 doesn't. If you used channel 1 for measurements in parallel with AWG sequence load, you need to turn it off as well as turn off the laser in the TopControl software since there are some internal conflicts. Otherwise, the problem might be in the "Digital in" input of the laser. It was already broken once and soldered back.
Laser software error	Reload the software. Reason: unknown.

	
Qudi "Timeout" error 	If all the required equipment is switched on, then you need to restart it (equipment). Reason: qudi can't connect to the equipment. Happens sometimes without visible reason probably due to MW/AWG internal problem.
Disconnection of the equipment. 	Add a USB PCI controller in the computer. Reason: the computer has problems with controlling a big amount of USB connectors, sometimes connecting new equipment disconnects one of the others. Power supplied USB hubs do not solve the problem.