PhyPiDAQ documentation (for teachers)

In this manual, the entire PhyPiDAQ workflow, starting from the Installation up to the evaluation of experiments is described.

1. What is PhyPiDAQ?

PhyPiDAQ is a project for transparent, easily understandable Data AQuisition (DAQ) with a Raspberry Pi. The software contains basic functions for data acquisition and visualization such as data logger, bar graph, XY or oscilloscope display and data recording on disk for subsequent evaluation.

The user interface is designed in such a way that pre-made templates for many sensors can be used to read them out quickly and easily. In addition, it also offers the option of changing parameters like, e. g. sampling rate, range, axis labeling, function evaluation for direct conversion of raw measurements of special sensor settings. The settings can be conveniently saved and recalled so that initial examples for own experiments or for a quick demonstration can be easily provided.

A large number of sensors, such as various analog-digital converters, current sensors, environmental data sensors, gamma ray detectors or a usb-oscilloscope, are supported. Here, widespread and inexpensive sensors were used, which have a sufficient level of accuracy that is more than sufficient for school experiments.

The sensors can be individually connected to the Raspberry Pi using jumper cables, or via a printed board specially designed for use with the PhyPiDAQ software on which some sensors and amplifiers are permanently attached. The latter set-up reduces cabling efforts to a minimum and experiments can be set up quickly. A 3d printed connection panel and a printed circuit-board are available so that all components can be conveniently provided in an organizer case.

Fig. 1: Representation of the time dependence of two signal sources (square wave and capacitor voltage) connected to an AD converter

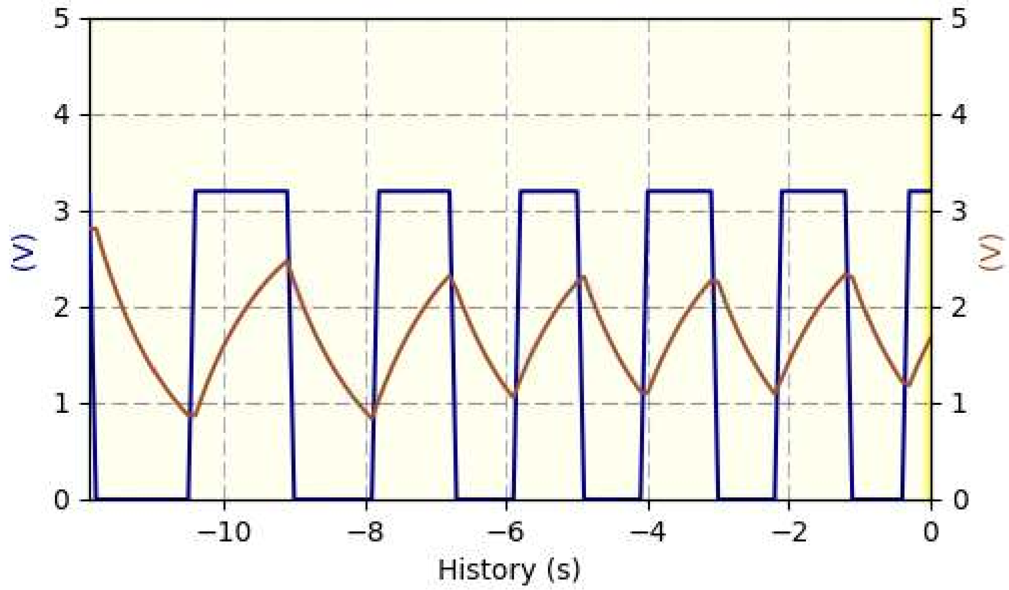
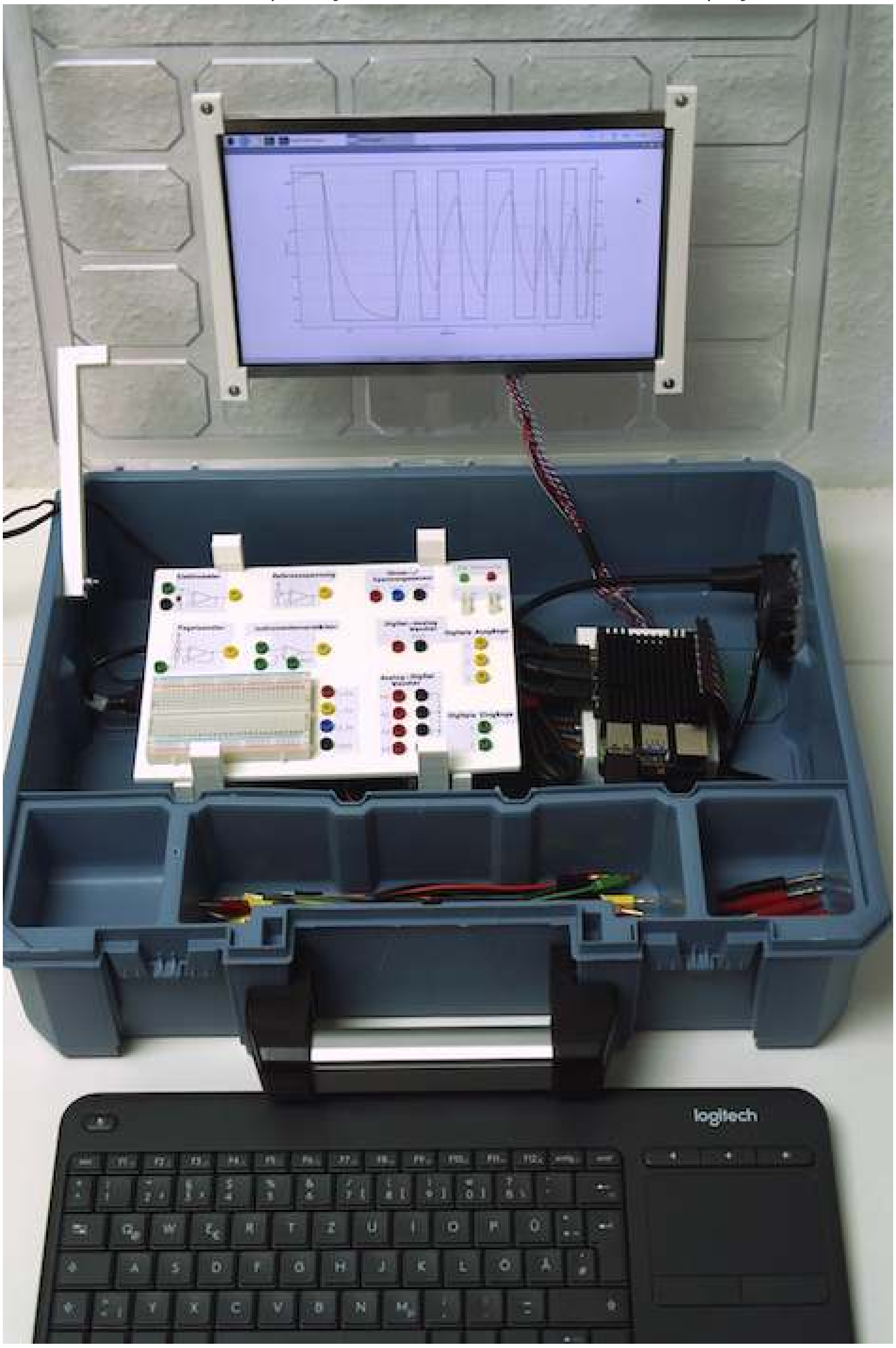


Fig. 2: Measurement case with Raspberry Pi, circuit board and built-in display



2. What do I need and how do I assemble it?

The software is open source and can be downloaded from this Github page.
The detailed installation is described here.

The following components are required for the measurement box:

2.1 Order list

Description	Order number	Quantity	Supplier	Unit price in euros	Total price in euros
for the plug-in board:					
Miniature socket, 2mm black	MBI 1 SW	9	Reichelt	0.79	7.11
Miniature socket, 2mm red	MBI 1 RT	8	Reichelt	0.79	6.32
Miniature socket, 2mm green	MBI 1 GN	8	Reichelt	0.79	6.32
Miniature socket, 2mm yellow	MBI 1 GE	9	Reichelt	0.79	7.11
Miniature socket, 2mm blue	MBI 1 BL	3	Reichelt	0.79	2.37
Arduino - Grove universal socket, 4-pin (set of 10)	GRV CONNEC4PIN	1	Reichelt	1.25	1.25
Standard LED green 5 mm	RND 135-00122	1	Reichelt	0.06	0.06
Standard LED red 5 mm	RND 135-00126	1	Reichelt	0.06	0.06
Breadboard 400 holes	RND 255-00005	1	Reichelt	1.90	1.90
Socket strip 2.54 mm, 1x20	MPE 115-1-020	4	Reichelt	1.20	4.80
Filament for 3D printer		120g			
for the board:					
PCB board "PhyPiDAQ"	https://aisler.net/p/ABFAPVWM	1	Aisler	approx. 10 euros	approx. 10 euros
Operational amplifier, 1-way, DIP-8	CA 3140 DIP	1	Reichelt	0.99	0.99
Instrumentation amplifier, 1-way, DIP-8	AD 623 ANZ	1	Reichelt	6.35	6.35

Description	Order number	Quantity	Supplier	Unit price in euros	Total price in euros
Seven Darlington Arrays, DIP-16	ULN 2003A	1	Reichelt	0.30	0.30
Operational amplifier, 2-way, DIP-8	MCP 6042-I / P	2	Reichelt	0.66	1.32
DC-DC 5V converter	TMA 0505D	1	Reichelt	5.50	5.50
Analog / digital converter ADS1115	RPI ADC 4CH	1	Reichelt	3.30	3.30
Rectifier diode	UF 4003	8	Reichelt	0.05	0.40
Level shifter	DEBO LEV SHIFTER	1	Reichelt	4.15	4.15
INA219 current / voltage sensor	DEBO SENS POWER	1	Reichelt	2.80	2.80
Digital-to-analog converter	802236543 - 62	1	Conrad	5.89	5.89
Resistance 10 kOhm, 1%	VI MBA 02040C1002	6	Reichelt	0.05	0.3
Resistance 1 kOhm, 0.1%	ARC MRA0207 1M B	2	Reichelt	0.37	0.74
Resistance 47 Ohm, 1%	VI MBB 02070C4709	6	Reichelt	0.03	0.18
Resistance 100 Ohm, 1%	VI MBB 02070C1000	1	Reichelt	0.04	0.04
Ceramic capacitor 10 nF	KERKO 10N	1	Reichelt	0.06	0.06
Ceramic capacitor 100 nF	KERKO 100N	4	Reichelt	0.06	0.24
Ceramic capacitor 100 pF	KERKO 100P	4	Reichelt	0.05	0.20
Electrolytic capacitor 47 µF	M-A 47U 100	4	Reichelt	0.21	0.84
Electrolytic capacitor 10 µF	KS-A 10U 16	4	Reichelt	0.11	0.44
Dot-strip grid board	H25PS200	1	Reichelt	2.60	2.60

Description	Order number	Quantity	Supplier	Unit price in euros	Total price in euros
IC socket 16 poles	MPE 001-1-016-3	1	Reichelt	0.35	0.35
IC socket 14 poles	MPE 001-1-014-3	1	Reichelt	0.29	0.29
IC socket 8 poles	MPE 001-1-008-3	4	Reichelt	0.26	1.04
Precision potentiometer	64Y-100K	2	Reichelt	0.21	0.42
Ribbon cable	RPI T-COBBLER P	1	Reichelt	3.60	3.60
for case and Raspberry Pi:					
Raspberry Pi 4, 2 GB RAM	RASP PI 4 B 2GB RAM	1	Reichelt	49.00	49.00
Raspberry Pi charger	GOO 56746	1	Reichelt	8.50	8.50
Display (optional)	RPI LCD 10.1HDMI	1	Reichelt	102.10	102.10
Power supply display	HNP 15-090L6	1	Reichelt	9.99	9.99
Power supply	DEBO BREAD POWER	1	Reichelt	4.50	4.50
Memory card 32GB	SDSQUAR 032GGN6MA	1	Reichelt	7.95	7.95
USB hub	DESKHUB 60-SW	1	Reichelt	6.00	6.00
HDMI cable	RPI M-HDMI HDMI	1	Reichelt	4.50	4.50
Filament for 3D printer		170 g			
Keyboard with mouse pad	LOGITECH K400PRO	1	Reichelt	29.95	29.95
USB A USB C cable	GOOBAY 55467	1	Reichelt	2.40	2.40

Description	Order number	Quantity	Supplier	Unit price in euros	Total price in euros
Cooling case Raspberry Pi passive	2140237 - 62	1	Conrad	15.49	15.49
Jumper cable	096853 - 62	1	Conrad	2.79	2.79
Insulating tape		1 roll			
Screws M2.5 20 mm		4			
Screws M3 12 mm		7			
Washers for M3 screws		14			
Pillar connector, 40-pin, with locking, angled	PSL 40W	1	Reichelt	0.49	0.49
Universal case	8519544	1	Hornbach	17.95	17.95
Accessories:					
Measuring line 15 cm red, 2mm	1385668-62	2	Conrad	2.49	4.98
Test lead 15 cm green, 2mm	1385671-62	2	Conrad	2.49	4.98
Measuring line 15 cm blue, 2mm	1385669-62	2	Conrad	2.49	4.98
Test lead 15 cm black, 2mm	1385667-62	2	Conrad	2.49	4.98
Test lead 15 cm yellow, 2mm	1385670-62	2	Conrad	2.49	4.98
Test lead 30 cm red, 2mm	1385676-62	2	Conrad	2.49	4.98
Test lead 30 cm black, 2mm	1385675-62	2	Conrad	2.49	4.98
Adapter plug, 2 mm plug / 4 mm socket, red	MZS2RT	2	Reichelt	1.45	2.90
Adapter plug, 2 mm plug / 4 mm socket, black	MZS2SW	2	Reichelt	1.45	2.90

Description	Order number	Quantity	Supplier	Unit price in euros	Total price in euros
Adapter plug, 4 mm plug / 2 mm socket, red	MZS4RT	2	Reichelt	2.30	4.60
Adapter plug, 4 mm plug / 2 mm socket, black	MZS4SW	2	Reichelt	2.30	4.60
Other:					
Superglue					
Heat shrink tubing					
Total:					
without display					284.52
with display					401.11

2.2 Building instructions

2.2.1 Soldering of the circuit board

First the socket headers (Reichelt, MPE 115-1-020) are clipped to the appropriate lengths. These are required:

- 3 x 1 pin
- 7 x 2 pins
- 1 x 3 pins
- 5 x 4 pins
- 3 x 5 pins
- 4 x 6 pins
- 1 x 10 pins

These are soldered to the corresponding holes marked by squares on the board. The other components are also soldered according to the labeling on the board. Pay attention to the polarity of the electrolytic capacitors - the side marked in white corresponds to the minus pole. Resistors and ceramic capacitors do not have any polarity. The brackets for the ICs are soldered in such a way that the semicircular recess matches the label. This shows in which direction the IC must be inserted.

In the picture on the left you can see two places for resistors and two for capacitors, which remain free. These are provided so that pull-up resistors and capacitors can be installed to ground in the event of interference on the I²C bus. But at first, these places should remain free.

Finally, the connection pins that are too long can be clipped off on the back. The components are placed on the respective brackets.

Fig. 3: soldering, step 1

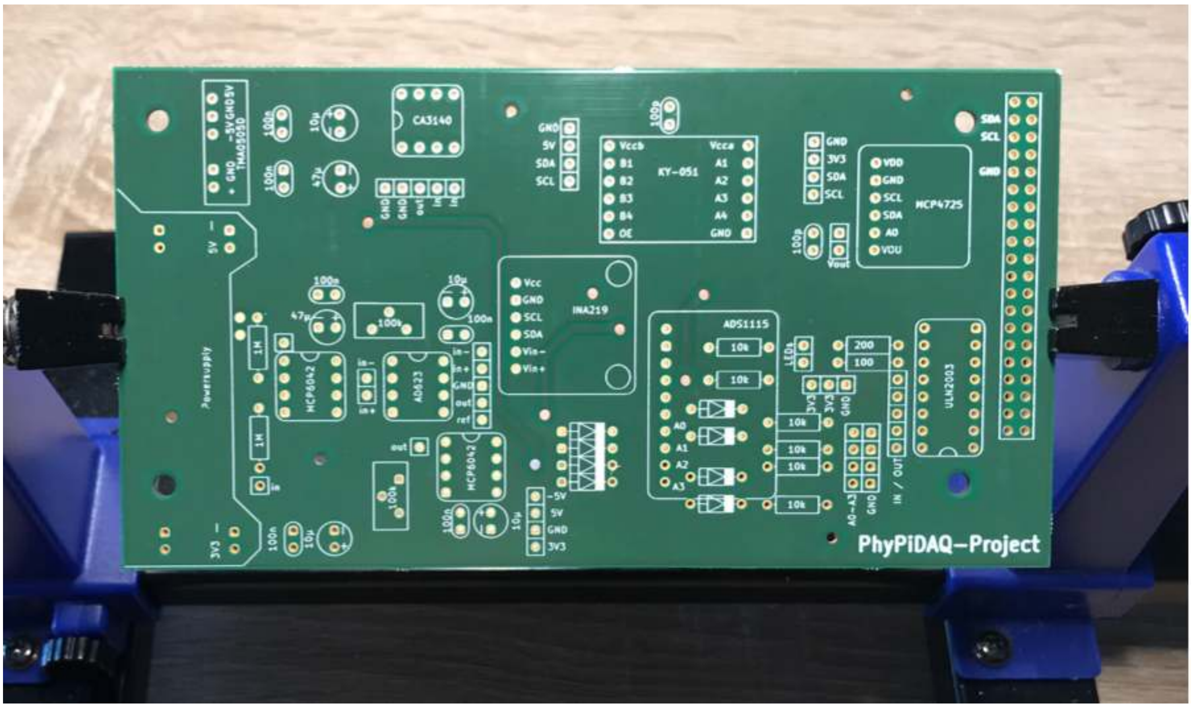


Fig. 4: Soldering, Step 2: The female headers are attached

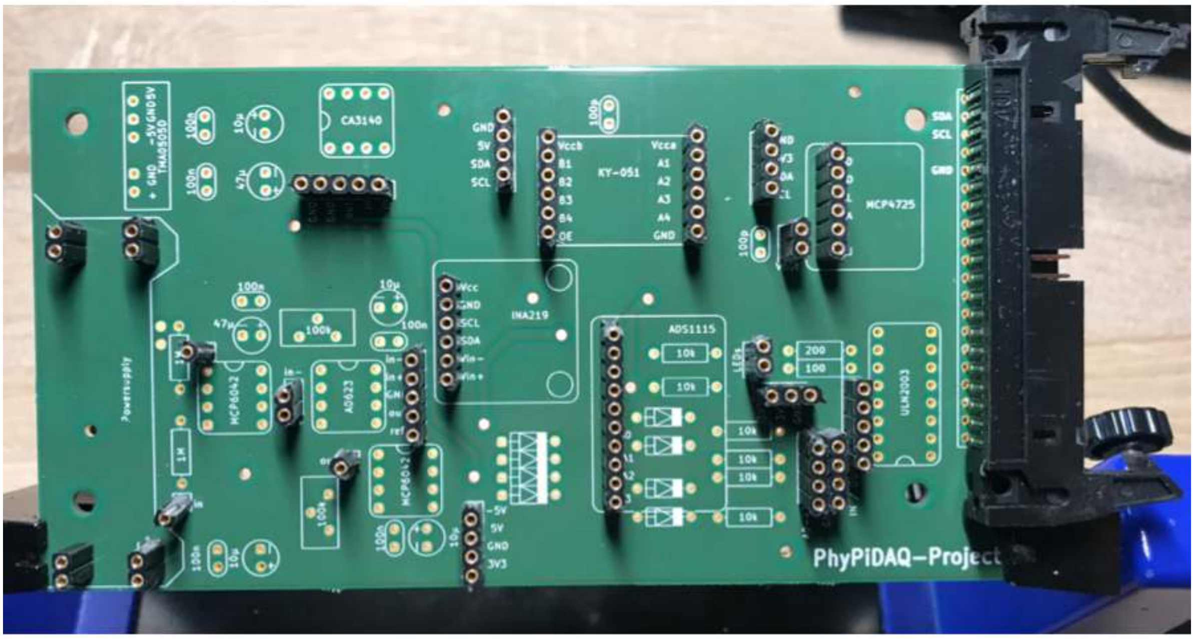


Fig. 5: Soldering, step 3: The other components are soldered on. The four devices marked in red are released

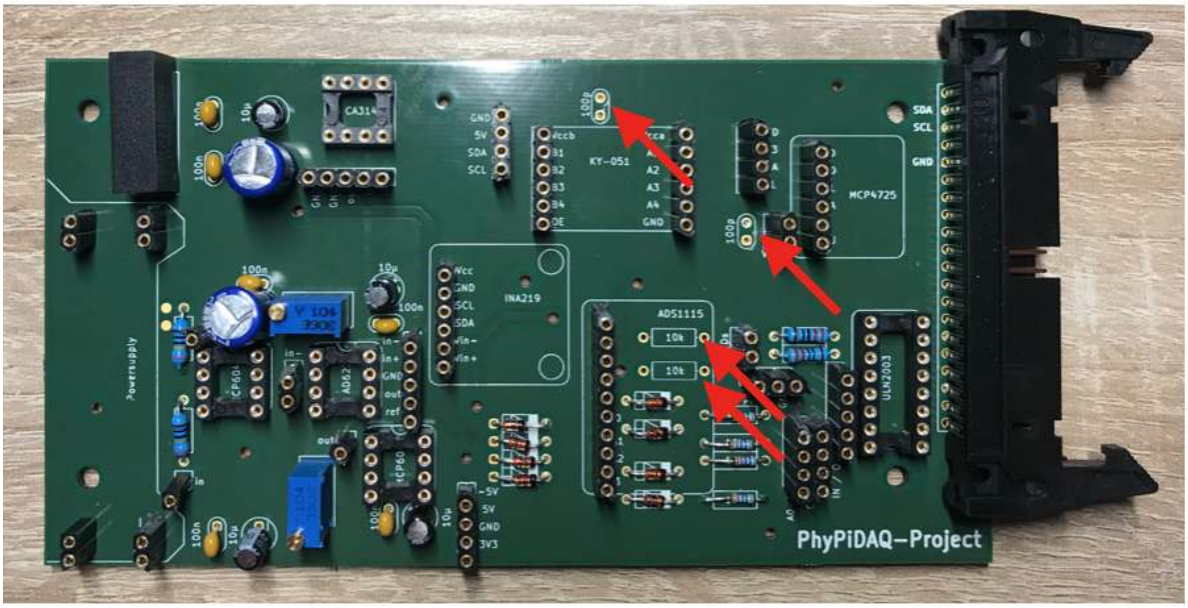
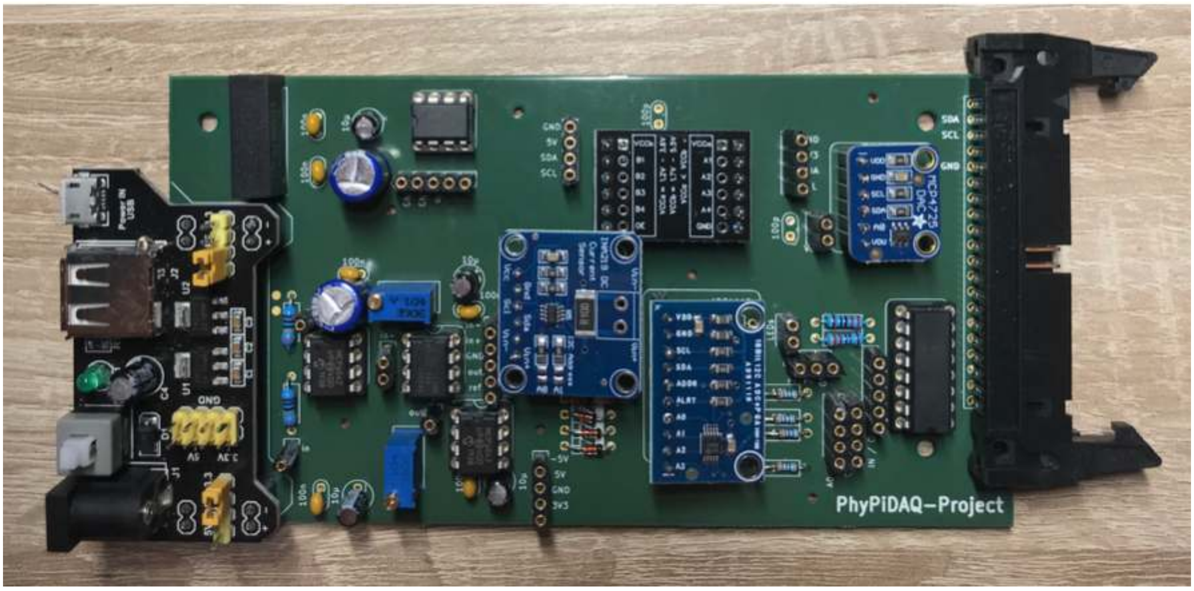


Fig. 6: soldering, step 4: the finished board



- Fig. 7*: The finished board with all components

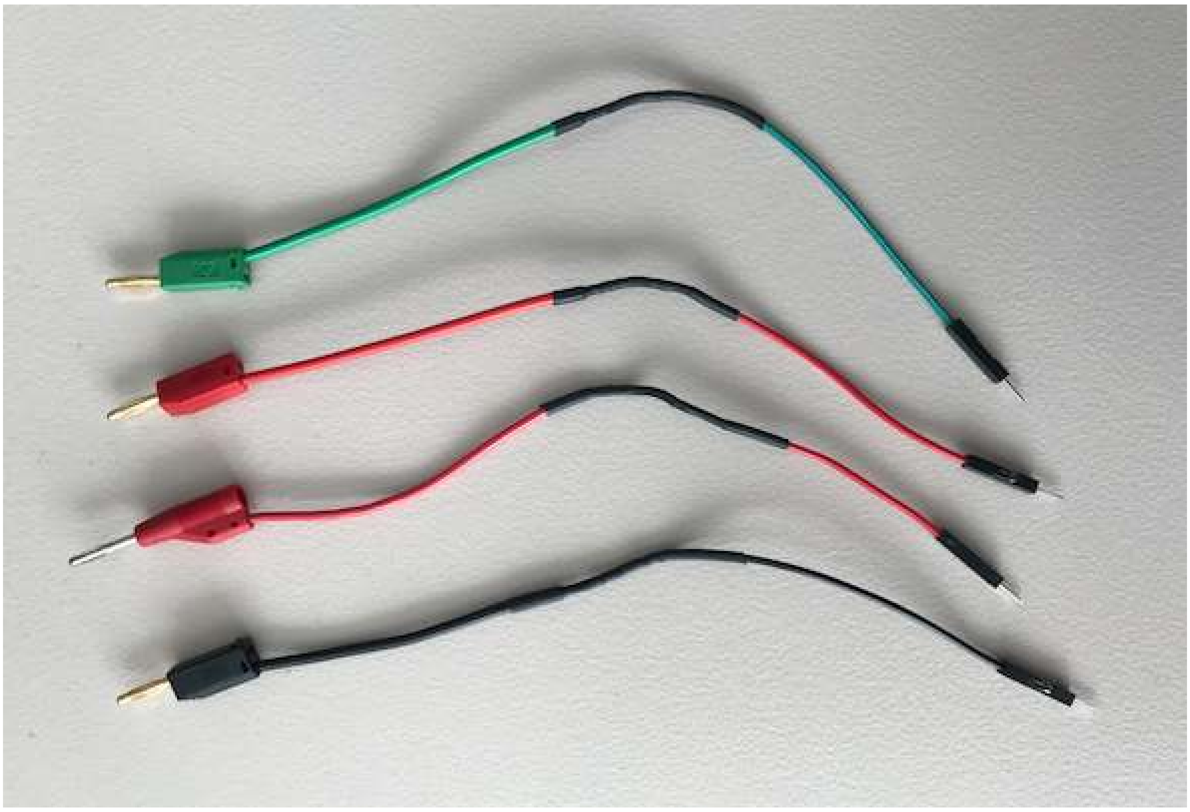
2.2.2 Building the case

The following part describes how the PhyPiDAQ hardware with the circuit board, an optional display and wireless keyboard can be attached to a standard organizer case, so that everything can be stored in a spacious, space-saving and secure manner.

First the 3D models are printed in the *Hardware/3D_Modelle* folder. Depending on the printer, it may be advisable to rotate the models accordingly and use a support structure. Good results have been achieved with PLA filaments. When the printed models are finished, the construction of the case can begin.

First, the 30 cm long breadboard connectors (C *, 096853-62) are cut once in the middle to obtain that 15 cm long cables. A total of 46 of such short cables are required. The cut side is stripped and soldered to the 32 2 mm sockets (R *, MBI1SW and other colors). The connectio pins of a red (R *, RND 135-00126) and a green LED (R *, RND 135-00122) are also soldered to the cables and insulated, as well as the two grove sockets (R *, GRV CONNEC4PIN) and two pin headers (R *, RPI HEADER 40).

Fig. 7: Box construction, step 1: Prepare plug connections



Next, the printed breadboard is drilled through with a 5mm wood drill in the designated places. The square cutouts for the Grove connections and the pin headers can be drilled through with a handpiece, for example.

The 2mm sockets can now be inserted and fixed with screws according to the illustration below. The LEDs, Grove sockets and pin headers are attached to the holes provided with superglue. The breadboard is attached to the connection panel with the adhesive tape on its back. The labels are printed out and glued at the appropriate places.

Fig. 8: Box construction, step 2: equipping the printed plug-in board with cables

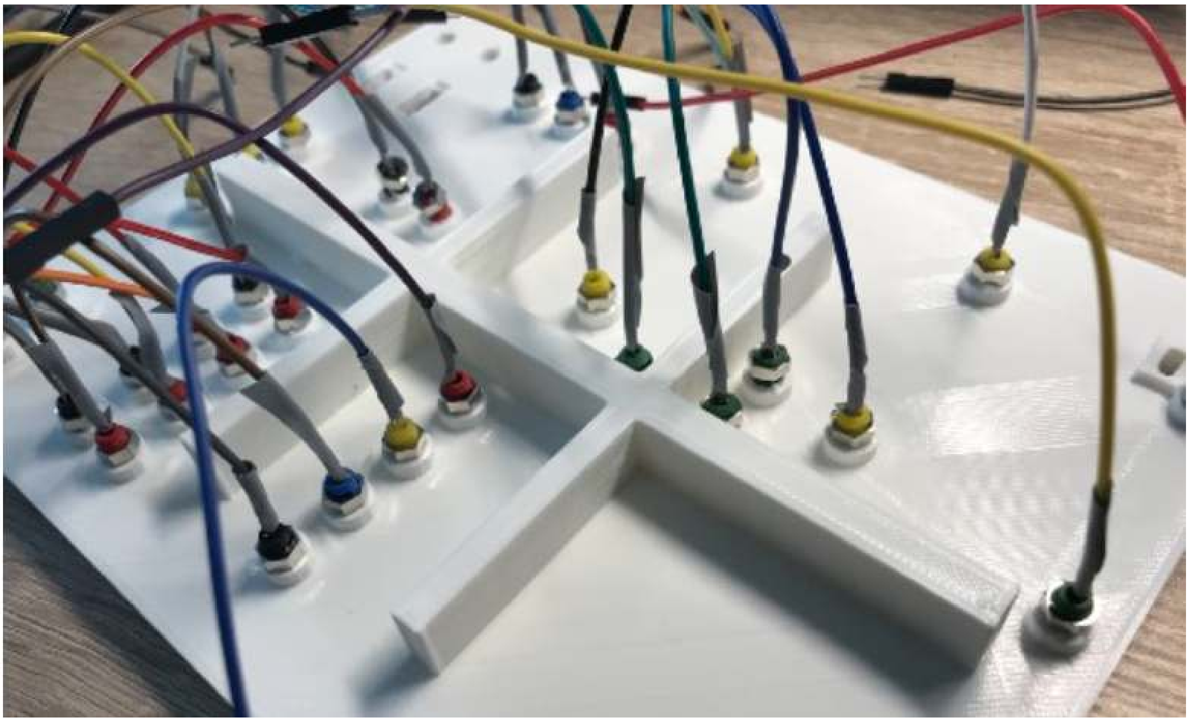
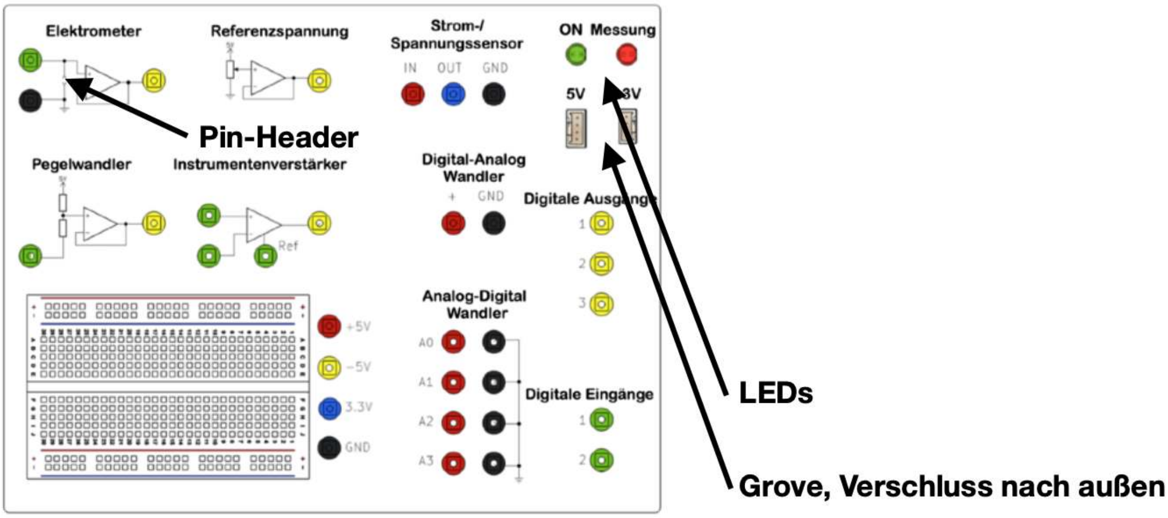


Fig. 9: Box construction, step 3: Stick the lettering on the plug-in plate

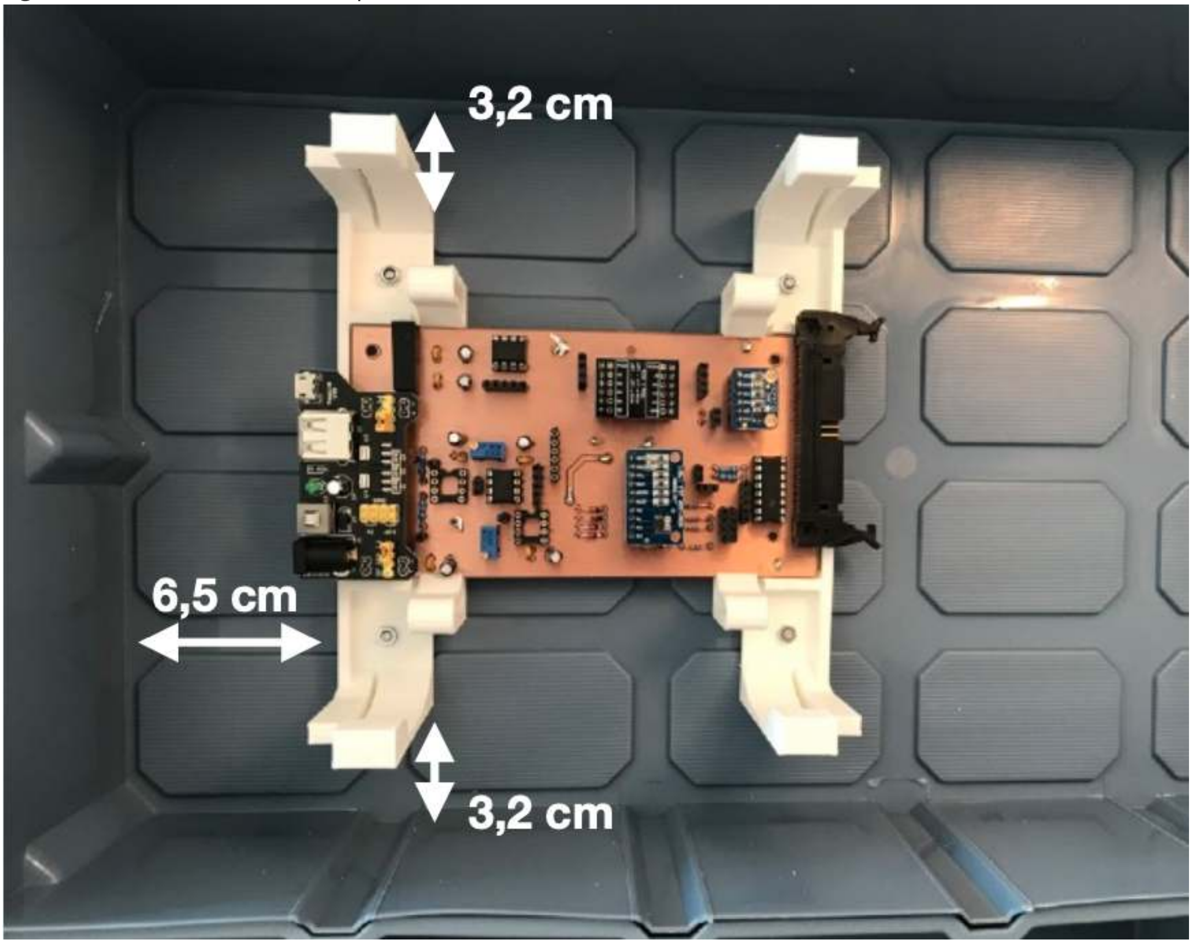


The case can be processed while the superglue is hardening.
First, the hole of the printed holding rod is drilled through with a 3mm drill. This is then drilled into the left inside of the case in such a way that the cover is held by the rod with slight pressure, thus preventing unintentional closing. A M3x16mm and lock nut can be used as a screw.

Fig. 10: Box construction, step 4: screw on the retaining rod


Now the brackets for the circuit board and the breadboard are screwed to the floor. For this purpose, the circuit board is clamped so that the spacing between the brackets is correct. The distance between the brackets in the back and front of the case should be 3.2 cm and 6.5 cm to the left. Suitable screws are M3x12mm, which are screwed upside down so they don't scratch the surface later.

Fig. 11: Case construction, step 5: Screw on the circuit board



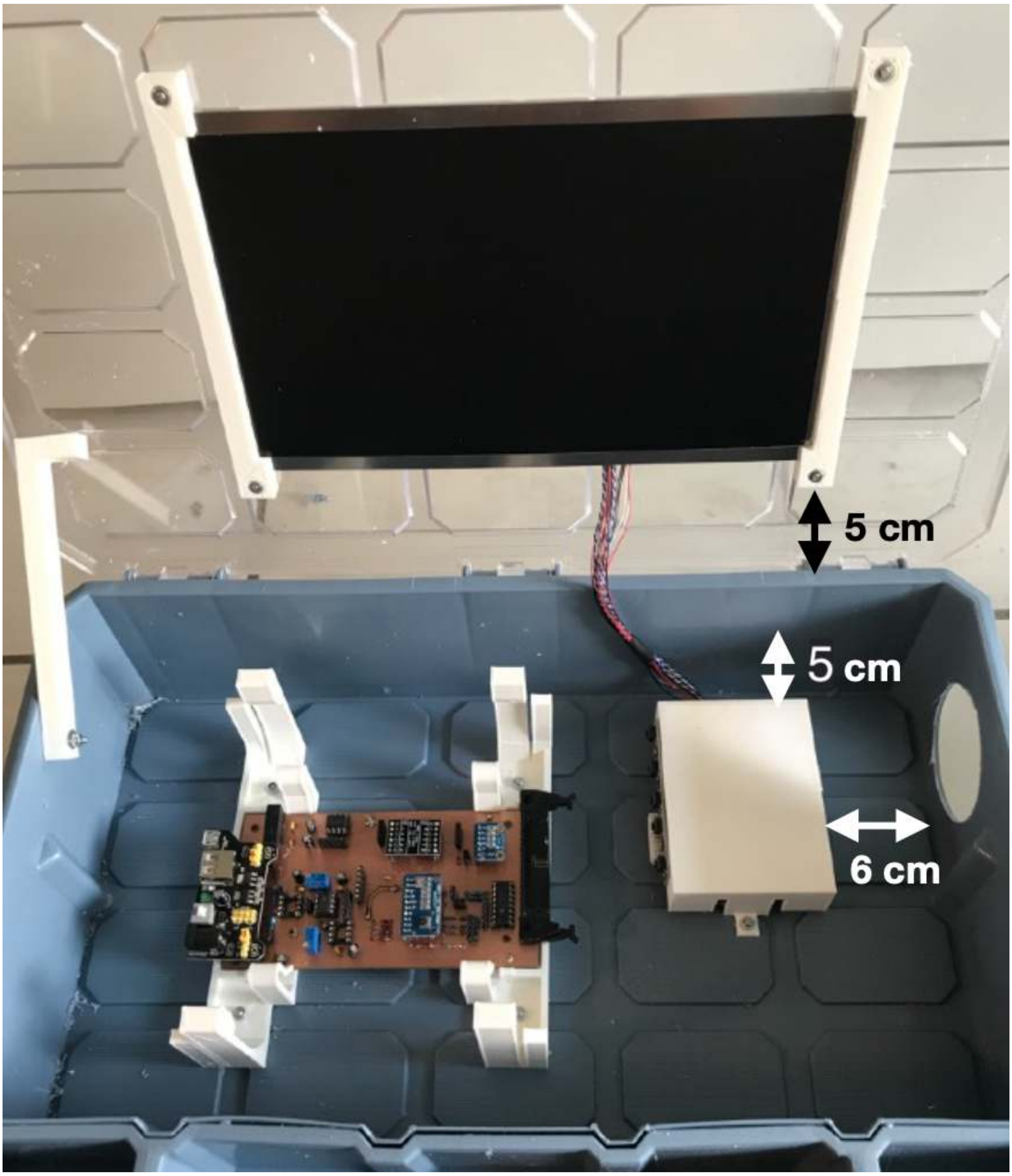
The hole for the USB hub (R *, DESKHUB 60-SW) is made with a 60 mm drill collar on the right side of the case at the back. The USB hub can now be glued into the socket with hot glue or super glue.

Fig. 12: Case construction, step 6: Drill a hole for the USB hub

Next, the display connected to the cable is clamped in the printed frame and attached to the cover with M3x10mm screws. The nuts point to the inside of the case. The distance from the display to the bottom is a maximum of 5 cm, so that the cables still reach the controller. The display controller is provided with the cables and the control unit is screwed to the printed bracket with M3x10mm screws. The controller can now be clicked in. The bracket can then be attached to the case with M3x12mm screws as shown in the illustration. The distance to the right should be at least 6 cm so that the connections are still accessible. In the case of a cable, the location on the controller is not clear. The color coding of the cables helps here: the red cables (mostly) represent positive voltages. The right place can be found with the labeling of the controller.

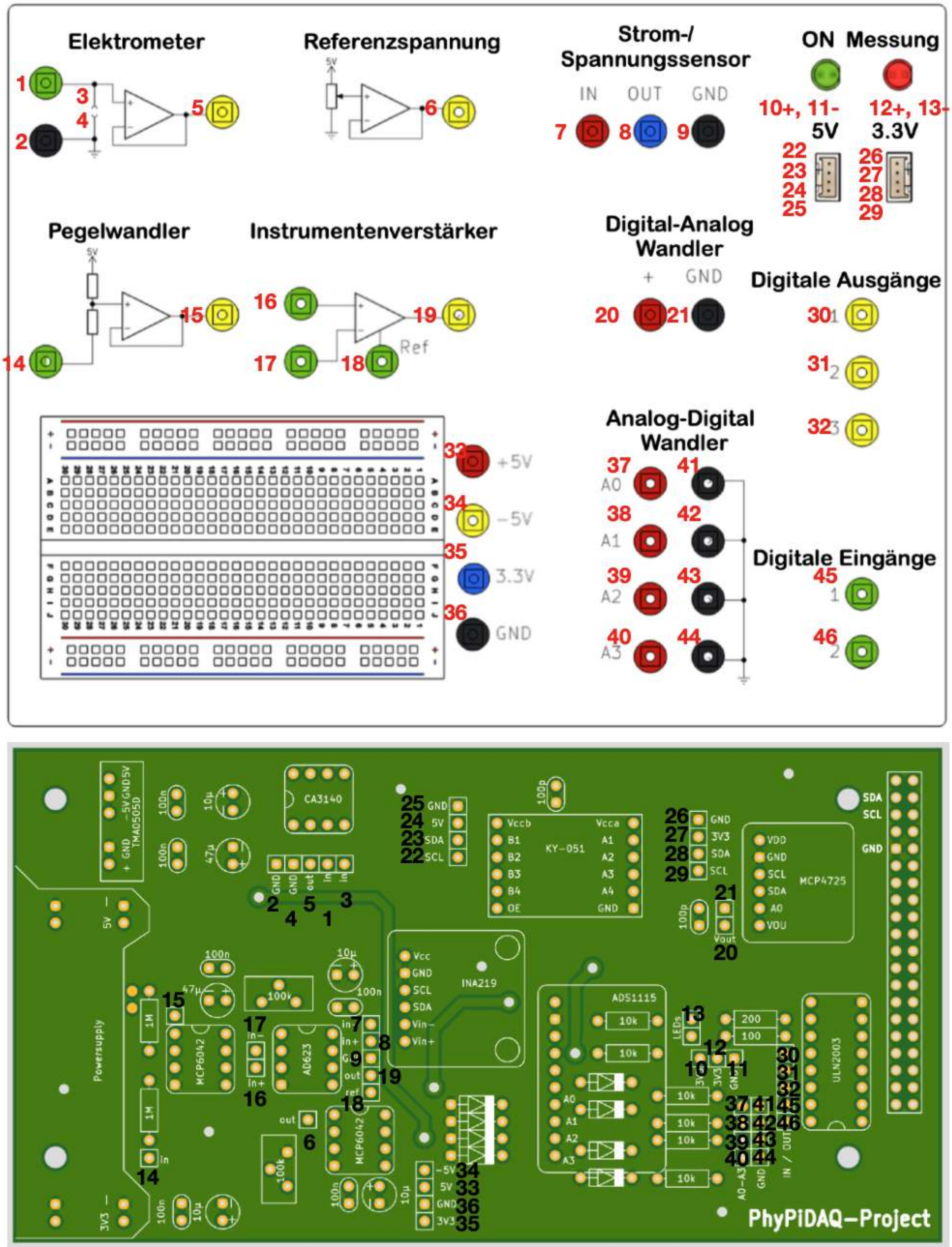
Fig. 13: Box construction, step 7: Wire the display controller

Fig. 14: Case construction, step 8: Screw on the display controller



When the superglue has dried, the plug-in board can be connected to the circuit board. The connections are shown below:

Fig. 15: Box construction, step 9: Wire the plug-in plate to the circuit board



Next, the Raspberry Pi is mounted. To do this, the Pi is first held in the right place on the display controller housing in order to put the drill holes on it. Then the cooling housing (C *, 2140237 - 62) is attached to the Pi. For this purpose, the three heat-conducting plates are attached to the appropriate places, whereby the foils on the top and bottom must be removed. The heat sink is screwed to the display controller bracket using the M2.5x25mm screws. The bracket with the Pi can now be attached to the case with M3x12mm screws.

Fig. 16: Case construction, step 10: attach Raspberry Pi heat sink

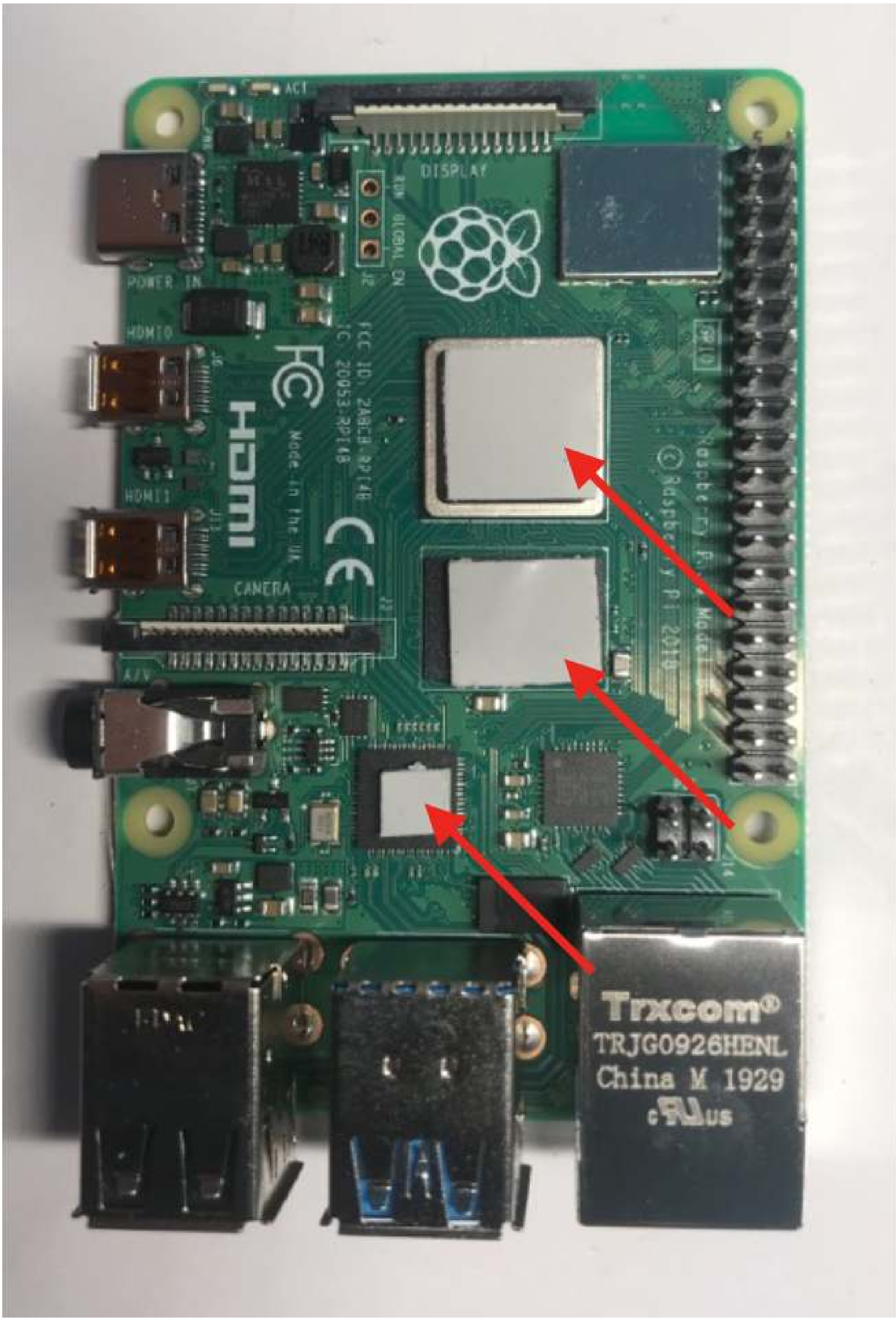


Fig. 17: Case construction, step 10: Screw the Raspberry Pi onto the display controller

Fig. 18: Case construction, step 10: Attach the display controller housing to the case

Finally, the Raspberry Pi is attached to the board via the extension pins (R *, RPI HEADER 40) with the 40-pin cable (C *, RPI T-COBBLER P). The power supply units for the board and display are also connected. The USB hub is connected to the Raspberry Pi. The dongle of the wireless keyboard (R *, LOGITECH K400PRO) is plugged into the USB port of the Pi. The HDMI port of the Raspberry Pi is connected to the display controller with the corresponding adapter (R *, RPI M-HDMI HDMI). The HDMI adapter (R *, DELOCK 65391) is plugged into the other port of the Raspberry Pi and can be fixed in the USB hub with adhesive so that another external display can be connected. The power port of the Raspberry Pi is connected to the power supply of the board (R *, DEBO BREAD POWER) with the adapter (R *, GOOBAY 55467). The keyboard can be stored on the plug-in board when the cover is closed. The cables and adapters are sorted into the three compartments.

Fig. 19: all parts with display and keyboard can be found in the case

3. How do I set up the Raspberry Pi and install PhyPiDAQ?

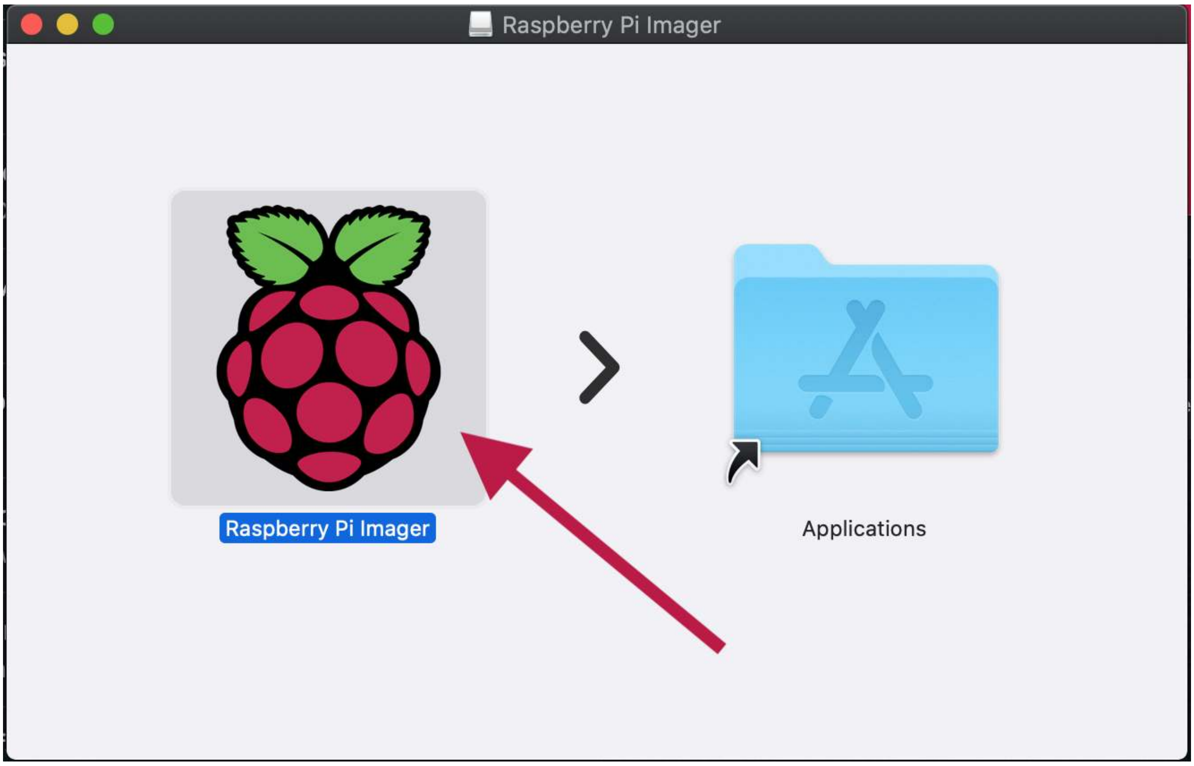
If there already is an operating system on the Raspberry Pi, you can continue directly with [3.2](#). If not, proceed with this description how to install the operating system.

3.1 How do I set up the Raspberry Pi?

First download *Raspberry Pi Imager* from the official website https://www.raspberrypi.org/downloads/ to any computer with an SD card slot.

Install the *Raspberry Pi Imager* by double-clicking the downloaded file.

Fig. 20: Installation of Raspberry Pi Imager, double click on the "Raspberry"



A new window opens in which you can select the operating system to be installed and the SD card. Under *Operating System* select "Raspberry Pi OS (other)" and then "Raspberry Pi OS Full".

Fig. 21: Selection of the operating system

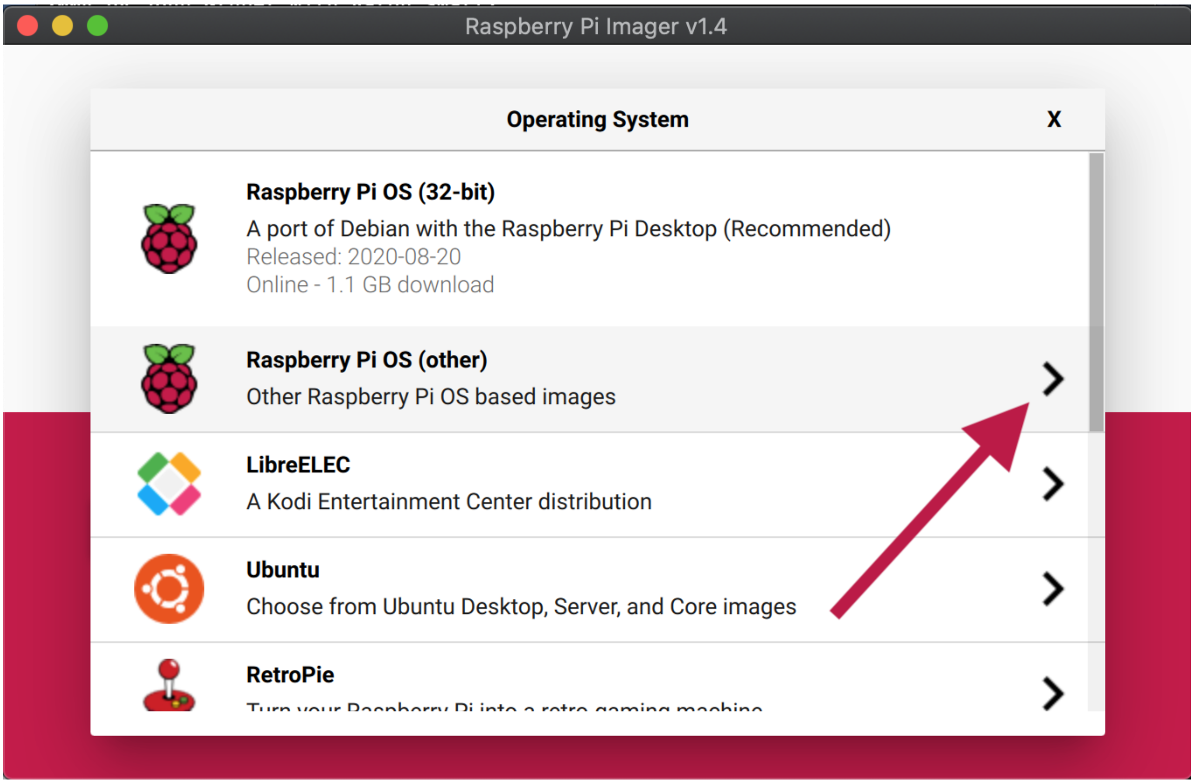
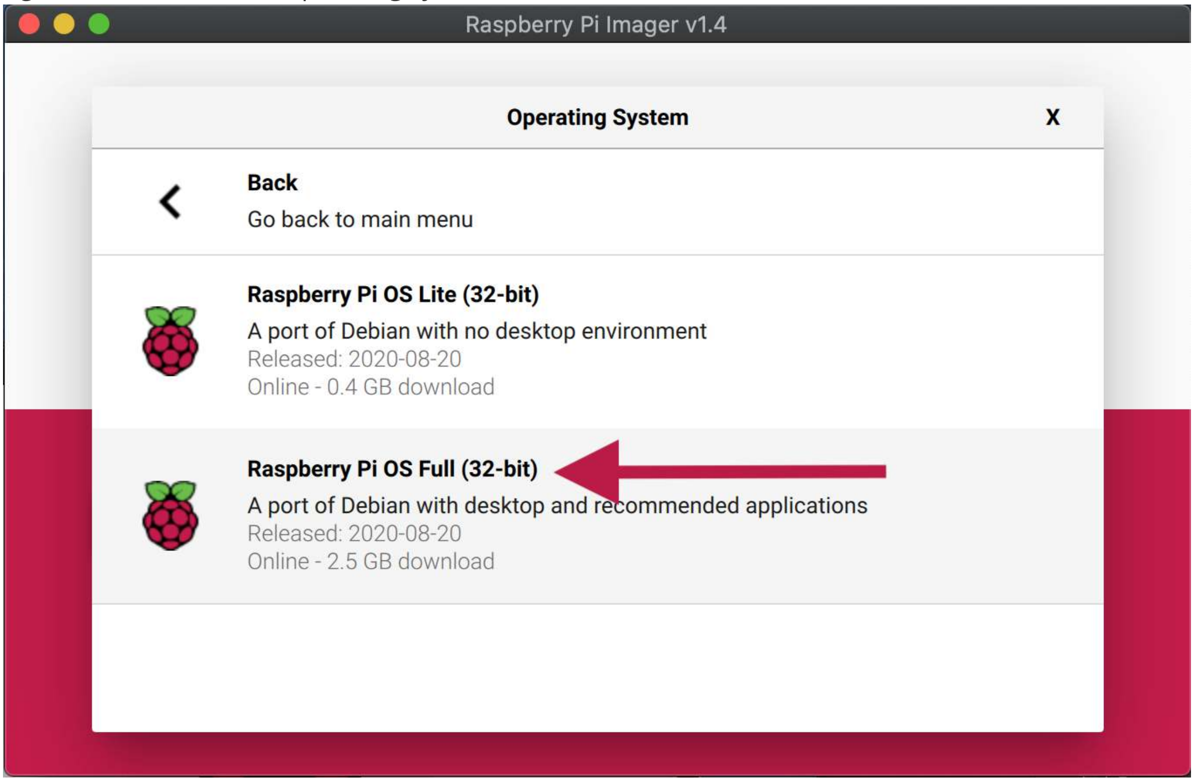
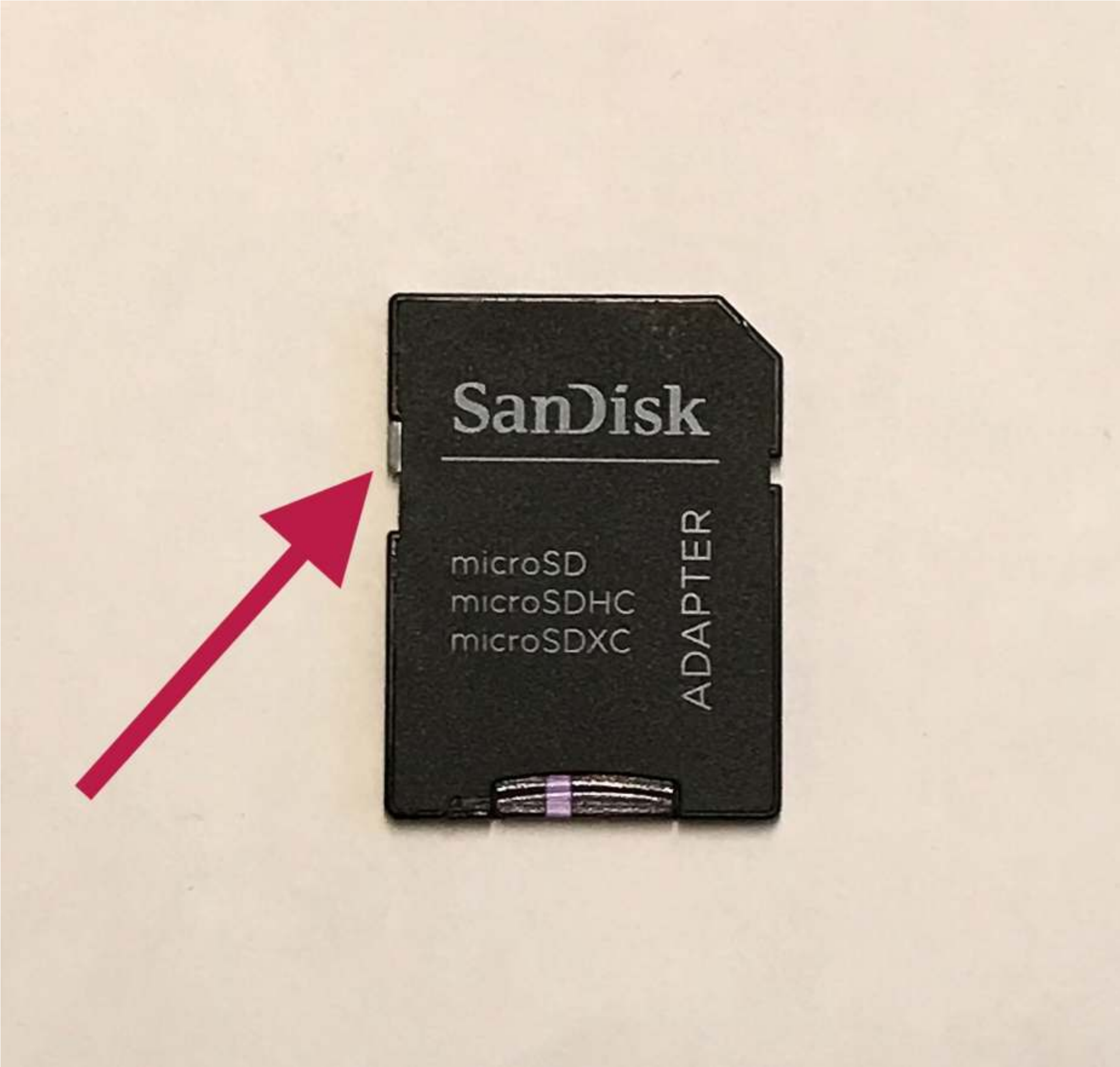


Fig. 22: Selection of the operating system



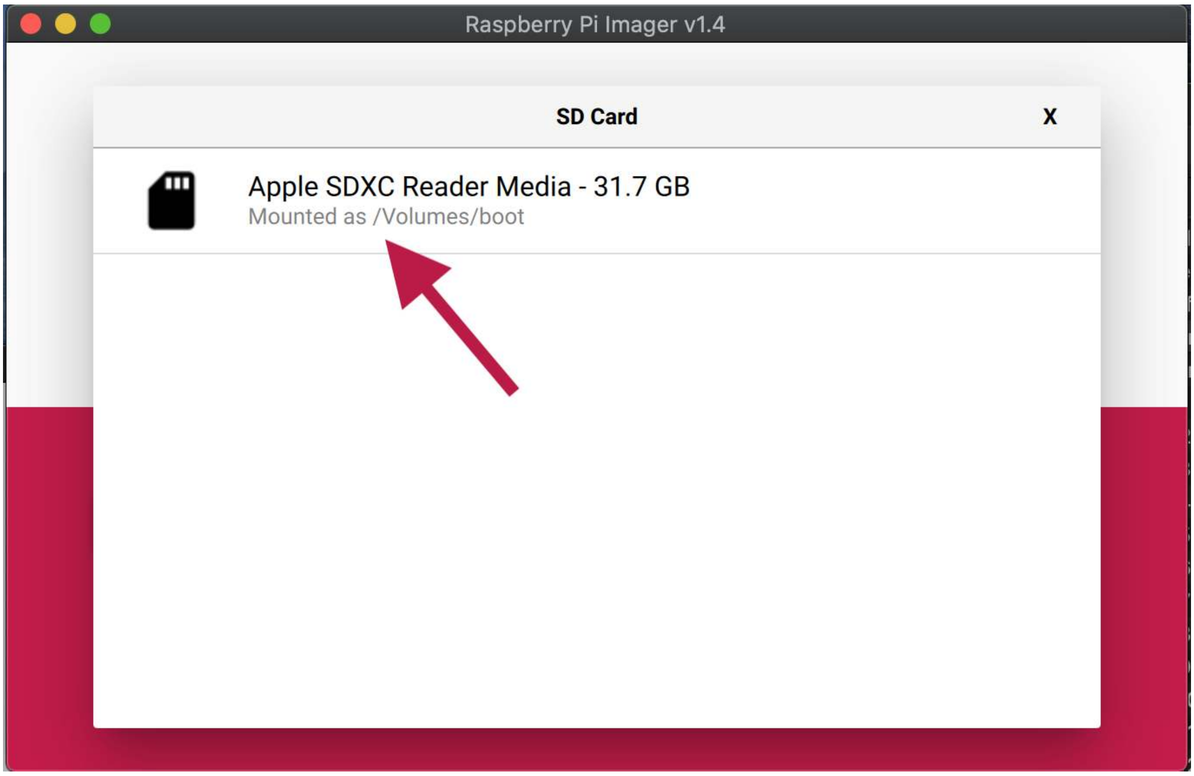
Insert the SD card into the slot of the computer. Ensure that the SD card is in writable mode by pushing the small slide on the left edge of the SD card adapter upwards.

Fig. 23: Make the SD card writable, move the slider to the top position



In the *Raspberry Pi Imager* you can now select your SD card by clicking on *"SD Card"*.

Fig. 24: Selection of the SD card



By clicking on *"Write"* and then confirming, you can finally record onto the SD card; you may be asked for the password once. This process can now take a few minutes.

Fig. 25: Writing to the SD card

When the process is complete, the operating system for the Raspberry Pi is on the SD card and this can be plugged into the Raspberry Pi. If you have not decided to use the case version with a display, connect an external monitor and make sure that a mouse and keyboard are connected. Also connect an

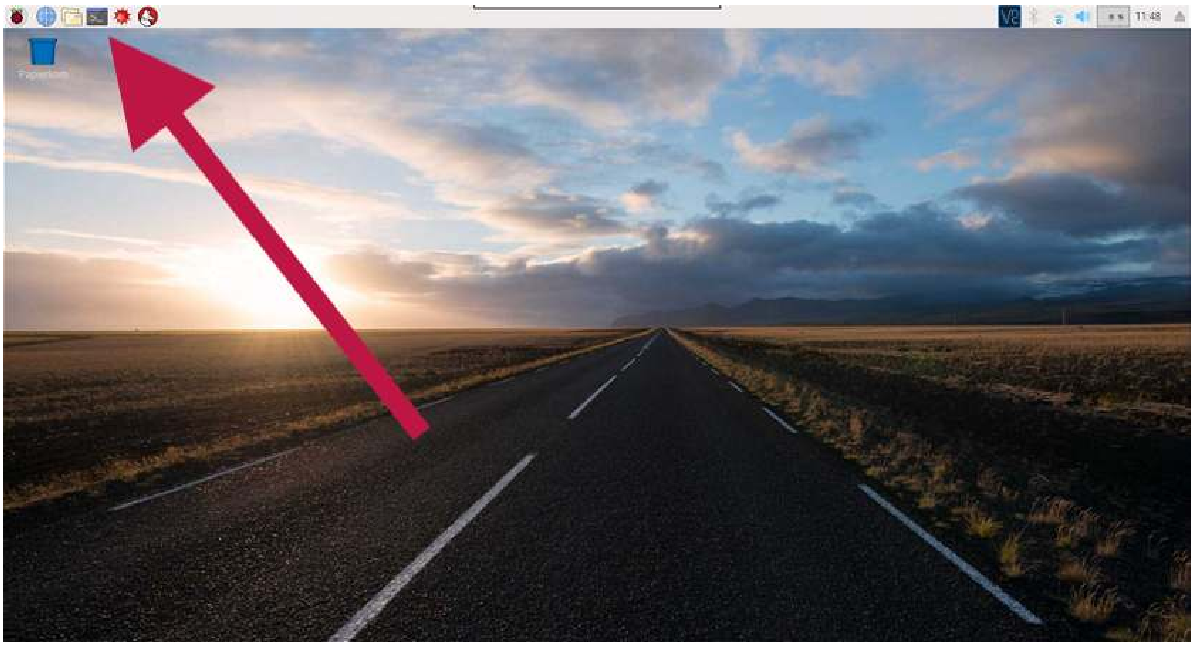
Ethernet cable if you don't have a WiFi connection available. Then you can connect the Raspberry Pi to the power supply, and it boots automatically. Various packages are now installed automatically, which can take several minutes. If this is successful, a window opens in which you can set basic system settings such as time zone, country, keyboard layout and your WiFi network, if this is desired. The installation of the Pi is now complete and we can continue installing *PhyPiDAQ*.

3.2 Installation of PhyPiDAQ on the Raspberry Pi

Obtaining the PhyPiDAQ code and easy installation

Please note that your Raspberry Pi must be connected to the Internet for the following steps. Open the terminal, which you can find in the system bar at the top left.

Fig. 26: Open the terminal

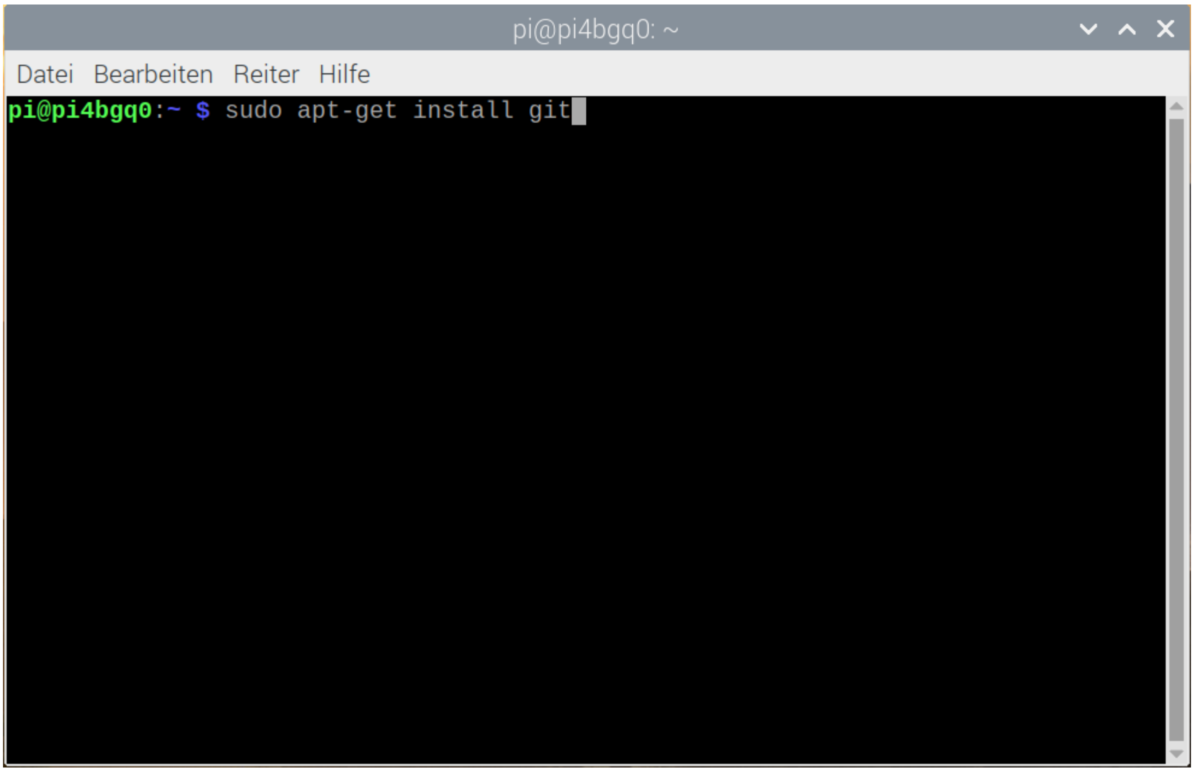


First install the repository manager *git*, which is used to download all files of the *PhyPiDAQ* package from its github repository.
To do this, enter the following texxt in the terminal window:

`bash`

`sudo apt-get install git`

Fig. 27: Enter command in the terminal



Enter the following commands to install *PhyPiDAQ*. Always copy this code line by line into the terminal and confirm each command with the Enter key. **DO NOT** insert all lines at once.

```
mkdir ~/git
cd ~/git
git clone https://github.com/GuenterQuast/PhyPiDAQ
cd ~/git/PhyPiDAQ
./installlibs.sh
cp ~/git/PhyPiDAQ/phypi.desktop ~/Desktop/
```

The installation is now complete and *PhyPiDAQ* is ready for the first use. If you want to update the installed version later, enter the following in the terminal (not necessary for the first installation, as the current version has already been downloaded):

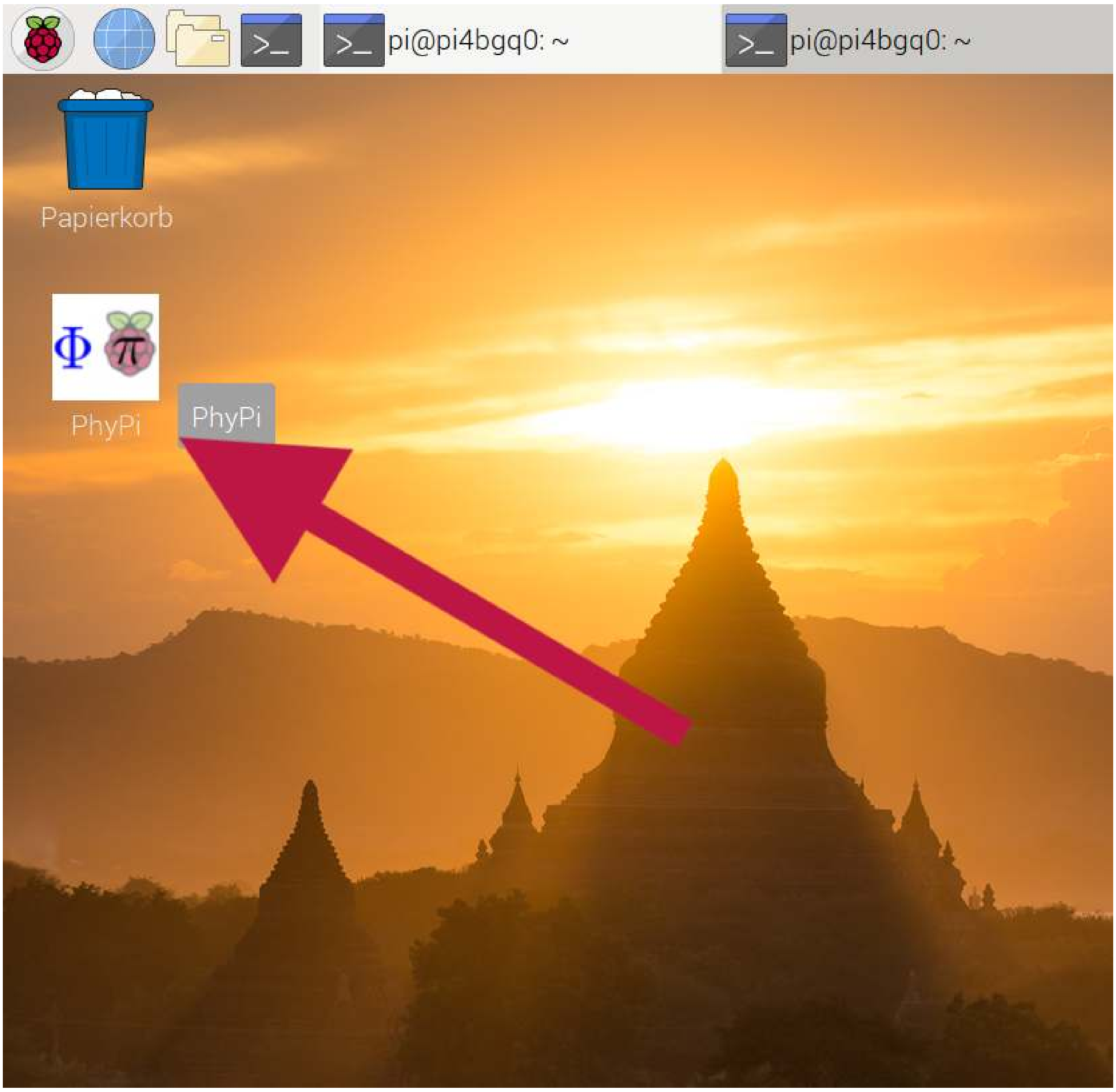
```
cd ~/git/PhyPiDAQ
git pull
./installlibs.sh
```

4. How do I use the PhyPiDAQ software?

4.1 starting surface

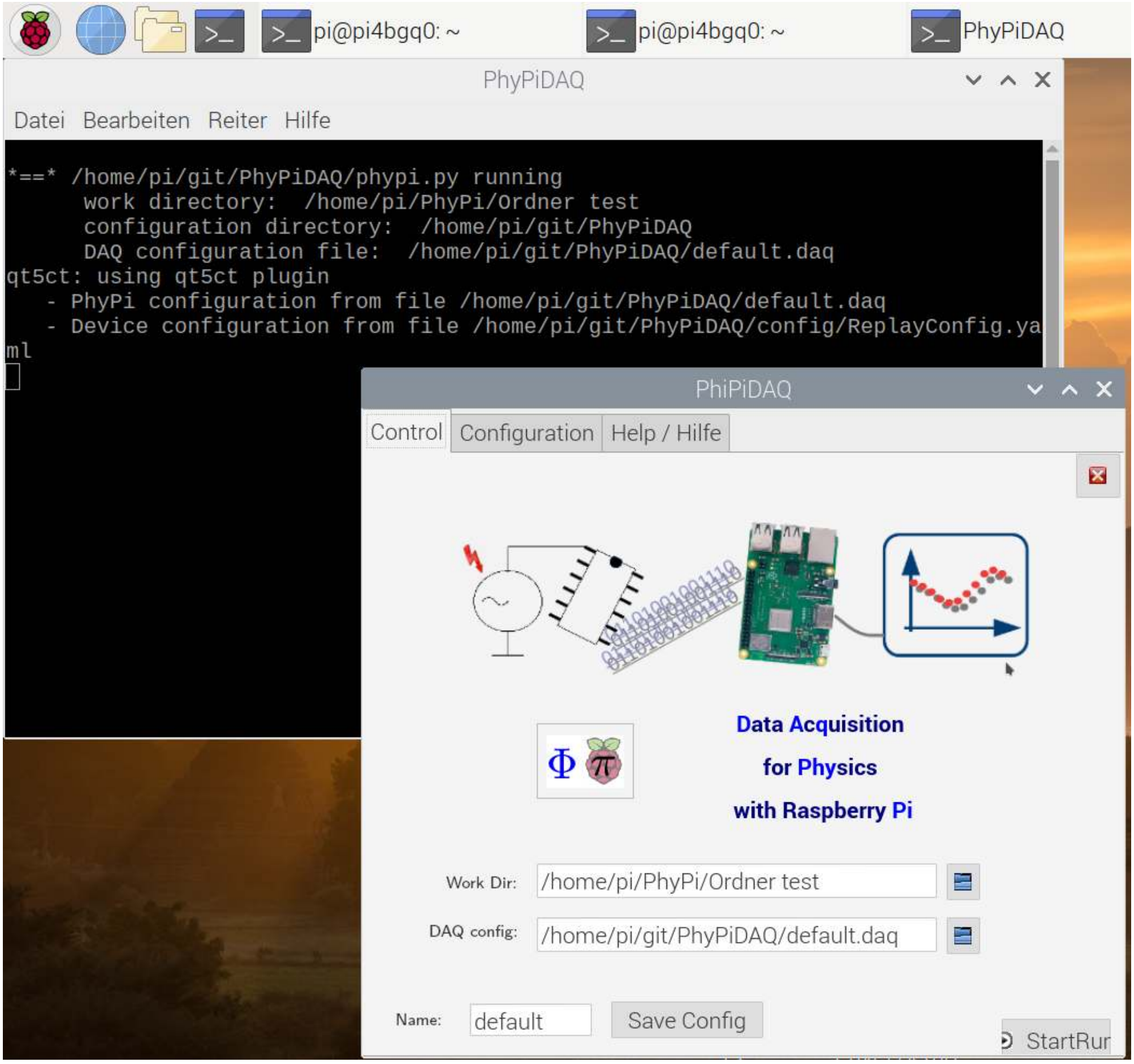
To start the *PhyPiDAQ* application, double-click the icon on the desktop **PhyPi**.

Fig. 28: Open PhyPiDAQ



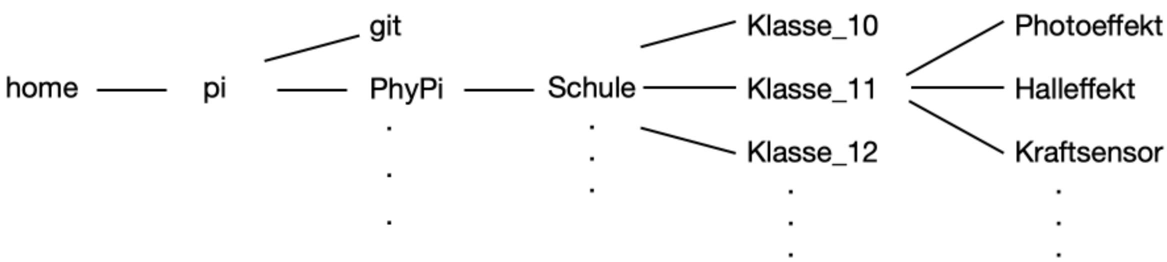
You will be asked how you would like to open it, select "*Run*" here. Two windows open now: a black terminal window, which shows current status messages and log files. You can ignore this window for ease of use. It only gets important when errors are displayed. In this case, the terminal window shows the error code and instructions which point to the problem and which can usually be used to fix the problem quickly. The more important window is the user interface of *PhyPiDAQ*.

Fig. 29: User interface *PhyPiDAQ*



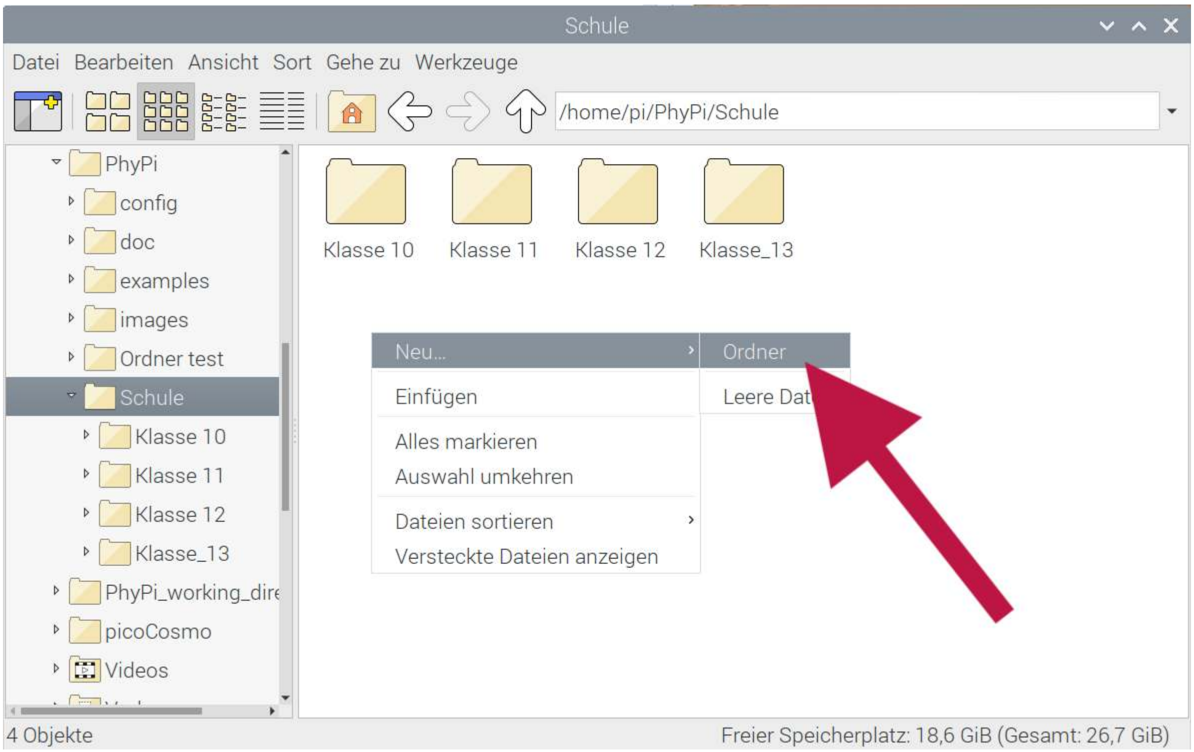
The tab "*Control*", in which you are after opening, is the start tab. A measurement can be started from here by clicking the button "*StartRun*" at the bottom right, but this should only be tried later. The so-called working directory can also be selected in this tab. Here you can determine where the configured experiment should be saved. A clear folder structure is essential if *PhyPiDAQ* is used in several school classes. So it is highly recommended to use a structure like the following:

Fig. 30: folder structure



You can create new folders in the file manager (similar to Windows "My Computer" or Mac "Finder") by right-clicking on *"New"* -> *"Folder"* in the window.

Fig. 31: create a new folder



Another possibility is to enter the following command in the terminal, which creates the subfolder *"class_12"* in the folder *"school"*.

```
mkdir /home/pi/PhyPi/school/class_12
```

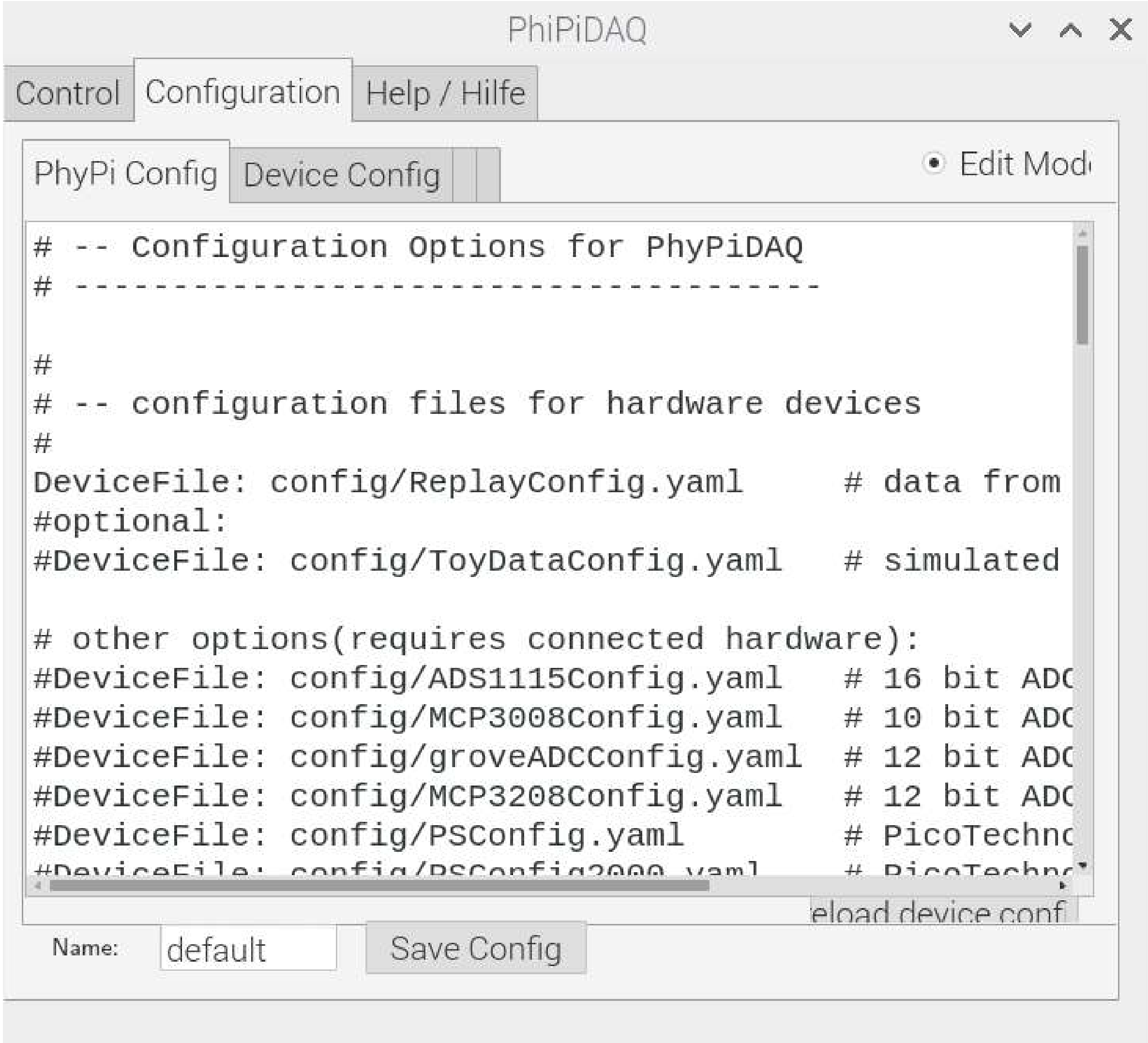
In the PhyPiDAQ user interface you select in the field *"Work Dir:"* in which folder you want to save the current project. Below that, in *"DAQ config*", you can open projects that have already been saved. This is particularly useful if you have already tested an experiment in advance and want to demonstrate it in class. The saved project will then be opened again in exactly the same way and you can start the experiment immediately. Below, in the field *"Name"* you can enter the name of the experiment. This will appear in the file name. If you click on *"Save Config"*, you save the configuration file. The file will then be called "default.daq" if you wrote "default" in *Name:*. Each time you start the program with "StartRun", an additional file is created with name, time and date, which is saved in the directory you specified for "Work Dir", e.g. school/class_12/photoeffect.

Task: Now create a folder structure as shown in Fig. 30 with your school classes. Create a folder with the name *"Test"* in one of these classes. Then switch to the *PhyPiDAQ* user interface and select the *test* you just created in *Work Dir*. Now assign the name "standard experiment" and save the project. Then verify in the file manager that the created project is there.

4.2 configuration file

We now want to familiarize ourselves with the second tab, *"Configuration"*. Click on the tab *"Configuration"*.

Fig. 32: configuration



A window can now be seen in which all parameters for the experiment can be set, such as:

- which sensor do I use (DeviceFile)?
- which maximum values should be displayed in the diagram (ChanLimits)?
- should the values of the sensor be converted directly (ChanFormula)?
- which axis labeling should be displayed (ChanLabels)?
- which formulas should be displayed (ChanUnits)?
- how often should be scanned (Interval)?

and many more...
Don't let this put you off! These parameters represent ways in which an experiment can be expanded or perfected. By no means all parameters are required - usually around 3-5 lines are sufficient. In the *"default"* - Config, which can be seen in Fig. 32, all setting options are indicated and can be commented out by a "#" at the beginning of the respective line.

If you want to make changes to this configuration, you must first activate the *"Edit Mode"* at the top right by clicking on it once.
The field in front of it shows that you can now write into the text field.
Helpful Keyboard shortcuts are:

- *Str + C* for copying selected characters
- *Str + V* for pasting the characters you just copied

- *Str* + *Z* for undo
- *Str* + *Shift* + *Z* to undo again.

Always start by telling the software which sensor you want to read out by removing the "#" at the beginning of the corresponding line.

We now want to read out the ADS1115 analog-to-digital converter demonstratively and therefore change the line

```
#DeviceFile: config/ADS1115Config.yaml   # 16 bit ADC, I2C bus
```

to

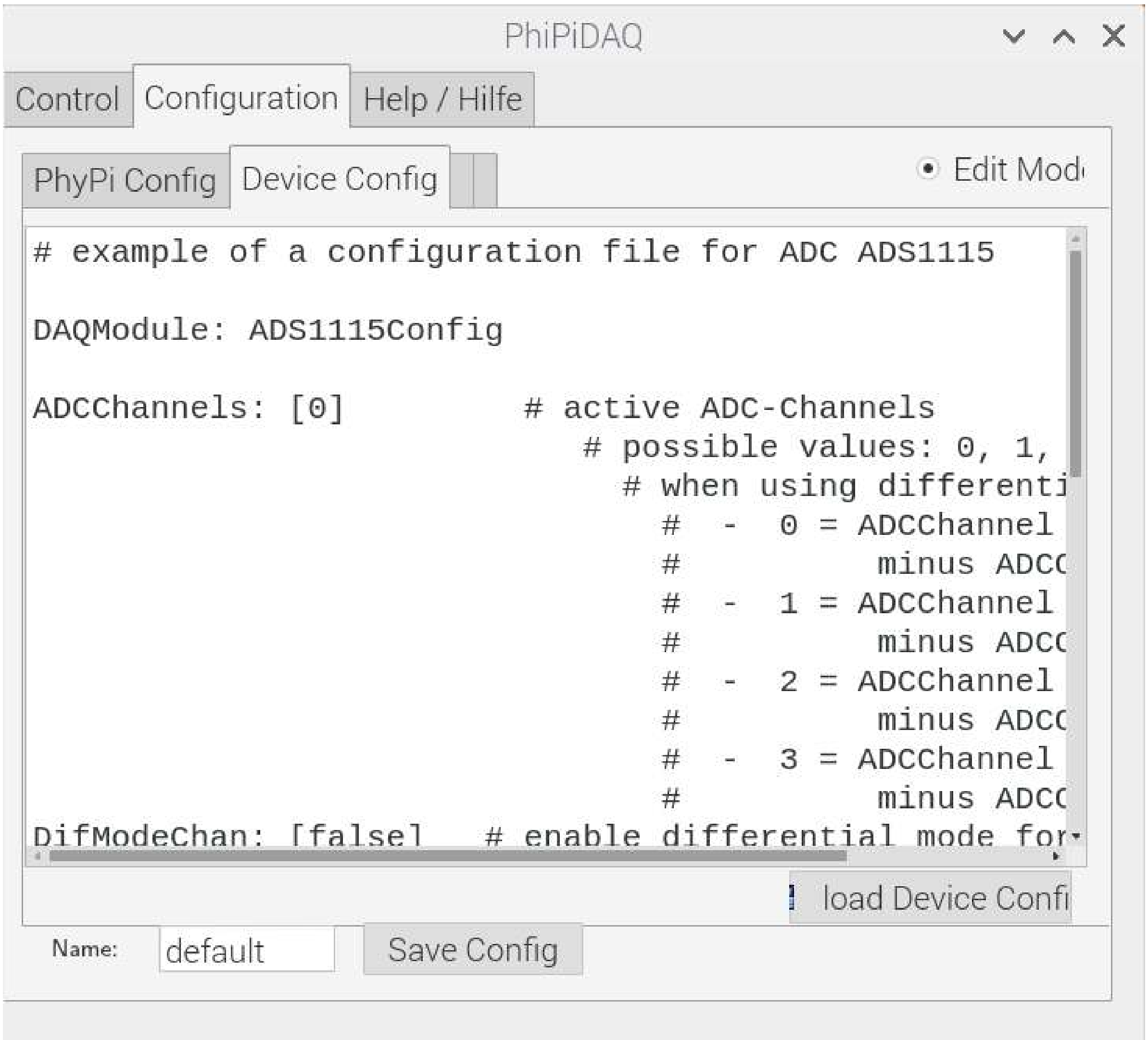
```
DeviceFile: config/ADS1115Config.yaml   # 16 bit ADC, I2C bus
```

You can leave all other settings here unchanged, as suitable parameters for this sensor are automatically selected. Changes may have to be made to the sensor, because e.g. it has four inputs but not all of them have to be read out depending on the project. To do this, click on *"reload device config"*, which you will find at the bottom right. A confirmation follows that *PhyPiDAQ* has now accepted the selected sensor.

4.2 Sensor configuration "Device-Config"

Now click on the tab *"Device Config"* at the top. The parameters of the sensor can be seen now.

Fig. 33: Configuration of the sensor



Here the syntax is the same again, that means:

- Lines that begin with "#" are commented out and have no function on the program
- To make changes you have to go to "Edit-Mode" by clicking above on the "Edit-Mode" field on the right.

You now have the choice of which channels you want to read out, what is determined in "ADCChannels". If you only want to read out channel 1, this is the line:

```
ADCChannels: [0]
```

because counting starts at zero. If you only want to read out channel 2, this is the line:

```
ADCChannels: [1]
```

You can read out several inputs at the same time by separating the individual channels with commas:

```
ADCChannels: [0, 1, 2, 3]
```

The other parameters below can be used if necessary, for example to subtract one input from another. To do this, follow the instructions in the corresponding lines. Please note that if you want to read out several channels, you also have to adjust the parameters below to the respective number of channels. So the following is not possible and will lead to an error message:

```
# example of a configuration file for ADC ADS1115

DAQModule: ADS1115Config

ADCChannels: [0, 1, 2, 3]         # active ADC-Channels
DifModeChan: [false]   # enable differential mode for Channels
Gain: [2/3]                # programmable gain of ADC-Channel
sampleRate: 860             # programmable Sample Rate of ADS1115
```

Correct is:

```
# example of a configuration file for ADC ADS1115

DAQModule: ADS1115Config

ADCChannels: [0, 1, 2, 3]         # active ADC-Channels
DifModeChan: [false, false, false, false]   # enable differential mode for
Channels
Gain: [2/3, 2/3, 2/3, 2/3]                # programmable gain of ADC-Channel
sampleRate: 860             # programmable Sample Rate of ADS1115
```

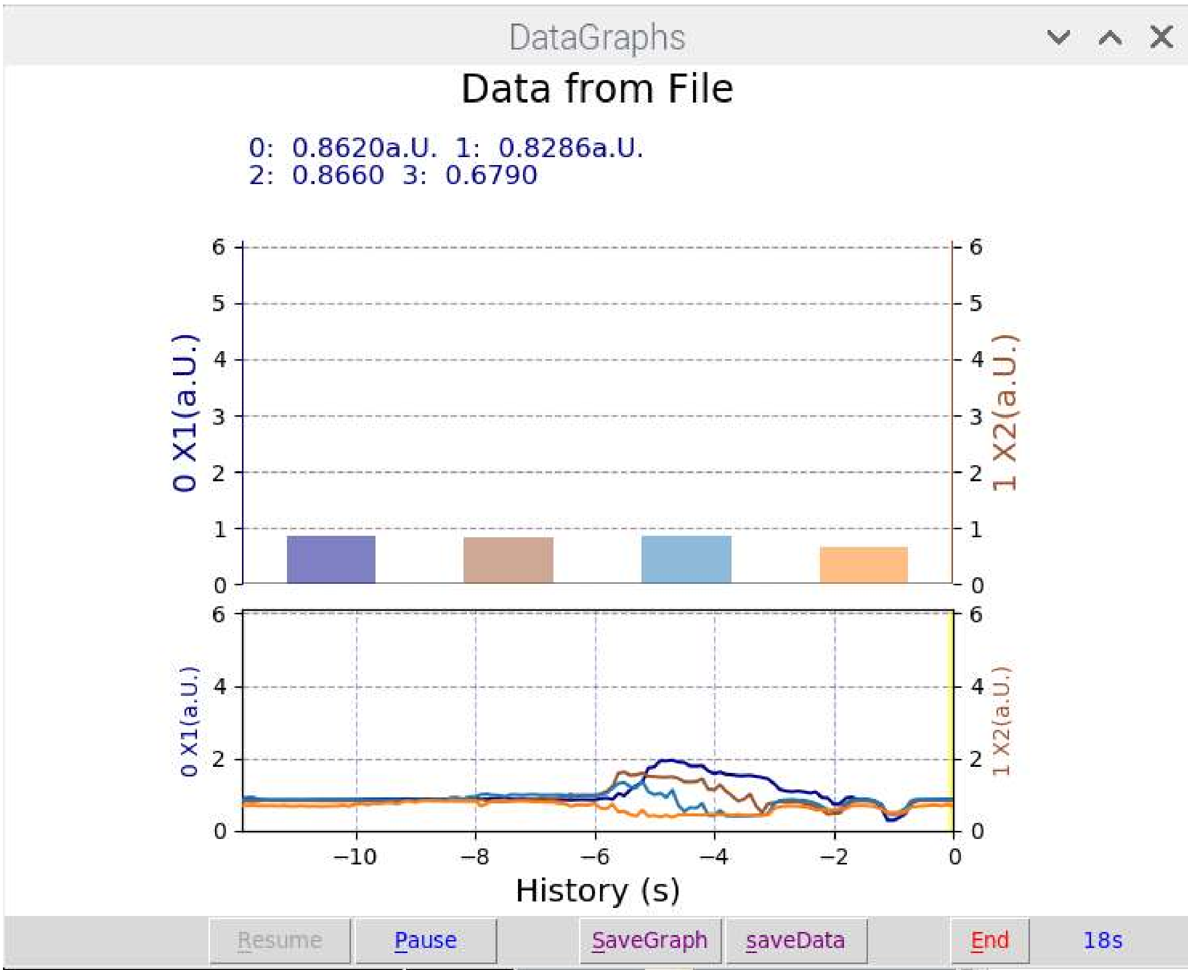
We have now selected the sensor *ADS1115* with four channels. You can now assign a name below and save the configuration.

Now connect the analog-digital converter to the Raspberry Pi - four wires are required: GND and + 5V for the power supply and SCL and SDA for the *i2C* connection, via which the sensor transmits data to the Pi.

4.3 Starting the measurement

Then you can click the button *"StartRun"*. A window with the diagram opens and you can start the measurement by clicking at the bottom left on *"Run"*. Congratulations, you have taken your first measurement with *PhyPiDAQ*!

Fig. 34: Reading out four channels with an analog-digital converter



There are now numerous ways in which you can use *PhyPiDAQ*. On the one hand, it is important to be able to save recorded data, which is done with *"SaveData"*. The values are saved in the folder selected in the working directory (*"WorkDir"*) in the folder belonging to the measurement. By default, only the first 12 seconds are saved, which is exactly the interval that can be seen in the display. In the configuration this can of course be adjusted and extended if desired. The standard data format is *".csv"*, which can also be adapted.

5. How do I carry out experiments with it?

We are now ready to read out a large number of different sensors, graphically plot them live on the monitor and export the values. That opens up countless possibilities to use *PhyPiDAQ* in the classroom. We will now describe three sample experiments so that you can see what the entire workflow can look like from start to finish.

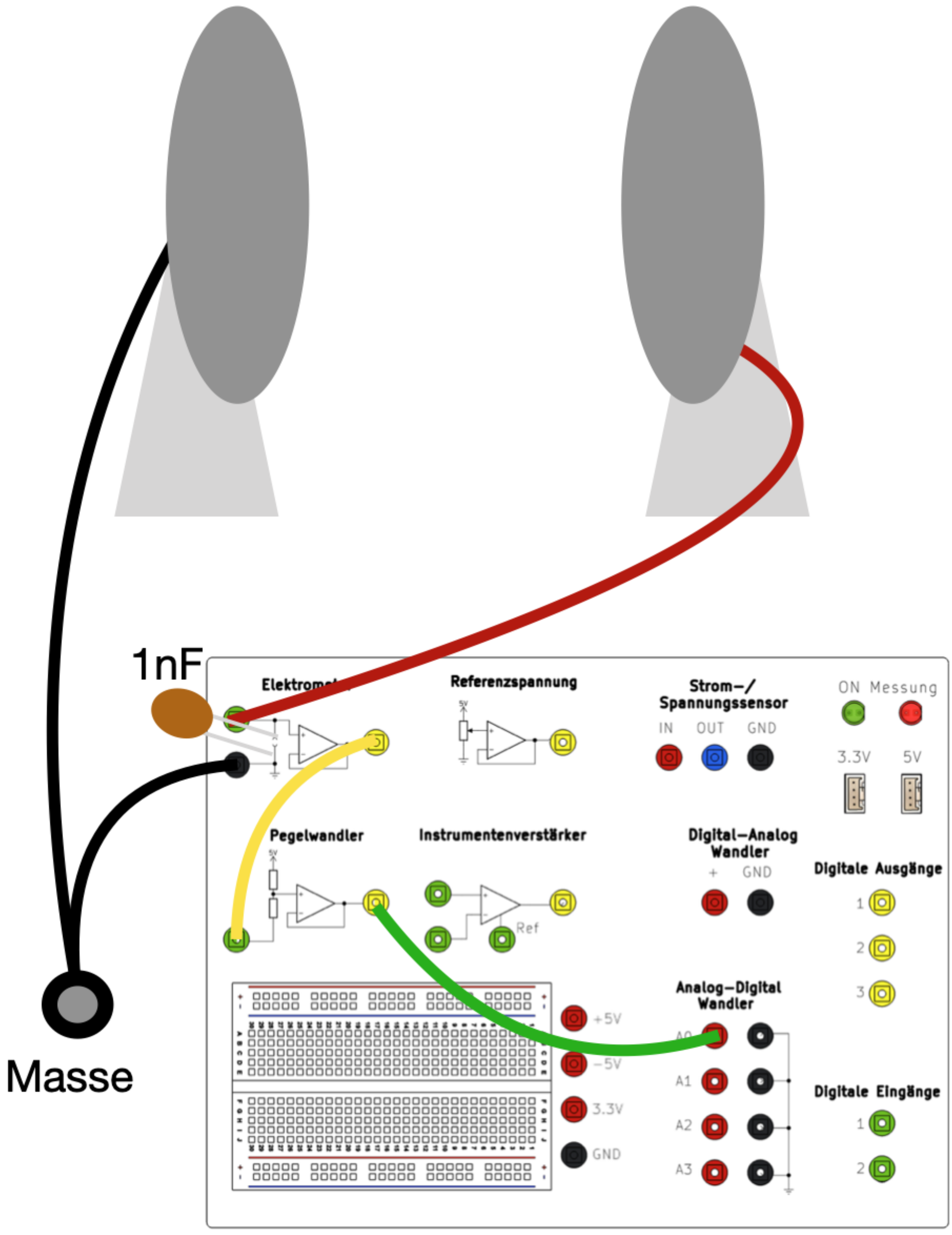
5.1 Electrostatics

In the following experiment, the effect of electrostatic influence will be shown. Furthermore, the same setup can also be used to demonstrate a load spoon.

An open, round capacitor plate with a diameter of d ≈ 5 cm is connected to the electrometer. The mass of the measuring case is pulled to the earth potential. A capacitor with a capacity of 1 nF is connected between the capacitor plate and the earth. The output of the electrometer is connected to the level converter and this in turn to the ADC. This means that both positive and negative voltages can be read out.

elektrostatik.daq:

Fig. 34: Electrostatic experiment setup



We now deal with the configuration file.

For the sake of clarity, superfluous comments and lines that have been commented out have been left out.

```
DeviceFile: config/myADS1115Config.yaml   # 16 bit ADC, I2C bus
ChanLabels: ['Uc']            # names for channels
ChanUnits: ['V']          # units for channels
ChanColors: [darkblue]      # channel colours in display
ChanFormula:
  - 2*c0-5  # chan0
Interval: 0.1                 # logging interval
DisplayModule: DataGraphs     # text, bar-graph, history and xy-view
Title: "Data from File"       # display title
```

myADS1115Config.yaml:

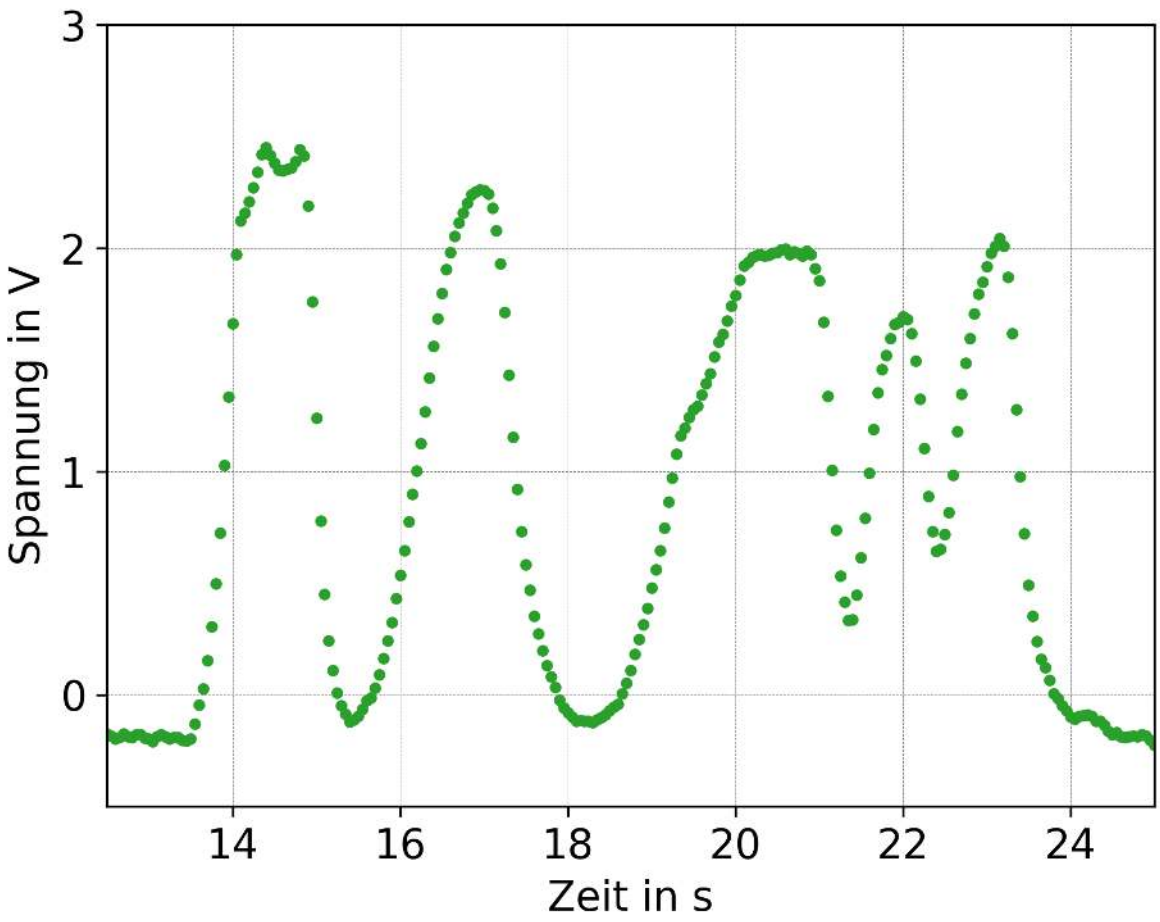
```
# example of a configuration file for ADC ADS1115

DAQModule: ADS1115Config

ADCChannels: [0]          # active ADC-Channels
DifModeChan: [false]    # enable differential mode for Channels
Gain: [1]                 # programmable gain of ADC-Channel
sampleRate: 860             # programmable Sample Rate of ADS1115
```

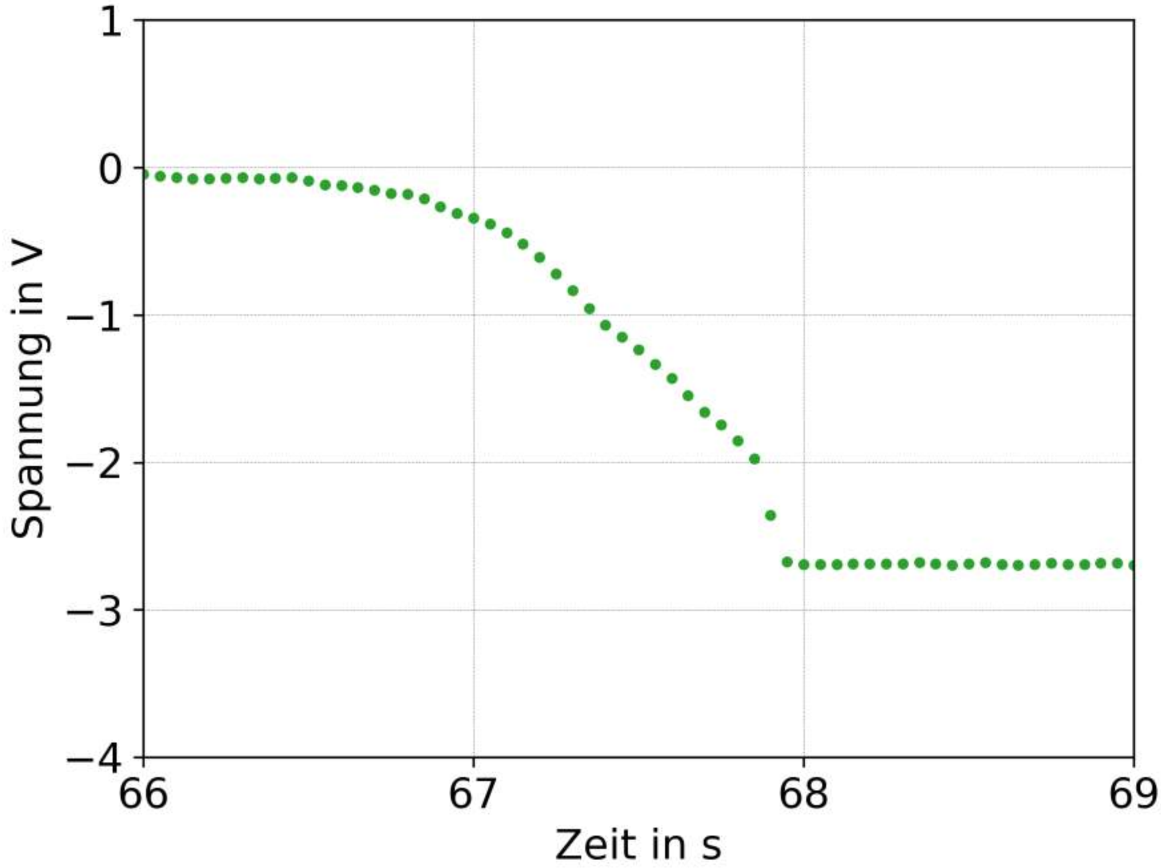
You may have to adjust the *Gain* in the penultimate line - depending on whether the displayed signal is too small or too large. On the software side, the function of the level converter is compensated as follows:
$U_{capacitor} = 2 \cdot U_{measured}$-5V, which is already taken
into account in *ChanFormula*. Before the measurement begins, the capacitor plate is connected to earth potential using a conductor so that it is uncharged. If a charged body is brought closer to the capacitor plate, the electric field of the charged body causes a force on the free electrons of the capacitor plate, which then - depending on the body's charge - are accelerated towards or away from it (influence). This process is limited by the fact that an electric field is built up through the charge shift, which counteracts the accelerating force. The charge separation can be measured as an electrical voltage that is applied between earth and the capacitor plate, i.e. precisely on the input side of the electrometer. It should be noted that an electrometer with a very high internal resistance is absolutely necessary for this experiment, as otherwise the greater current flow between the input of the electrometer and the earth leads to a charge equalization on the capacitor plate and the effect is therefore not visible. The effect is not visible with a conventional multimeter. A plastic rod is used as the body, which was rubbed on a wool sweater so that it became charged. Then it is brought closer to the capacitor plate, the distance being varied several times. The curve recorded in the figure below shows the time course of the voltage across the capacitor. The change in tension with the distance between the rods can be clearly seen. The sign of the voltage also shows that the rod is positively charged.

Fig. 35: **Influence** Time curve of the voltage on the capacitor with repeated changes in the distance to the charged rod.



Now the demonstration of the load spoon follows. To do this, a metal ball is rubbed on a wool sweater and then the discharged capacitor plate is touched with it. The illustration shows the course of the voltage. The increase in the capacitor voltage upon contact with the sphere indicates the charge. With Q = C · U, a known capacitance of 1 nF and the voltage difference of −2.7 V, the transferred charge is −2.7 nC.

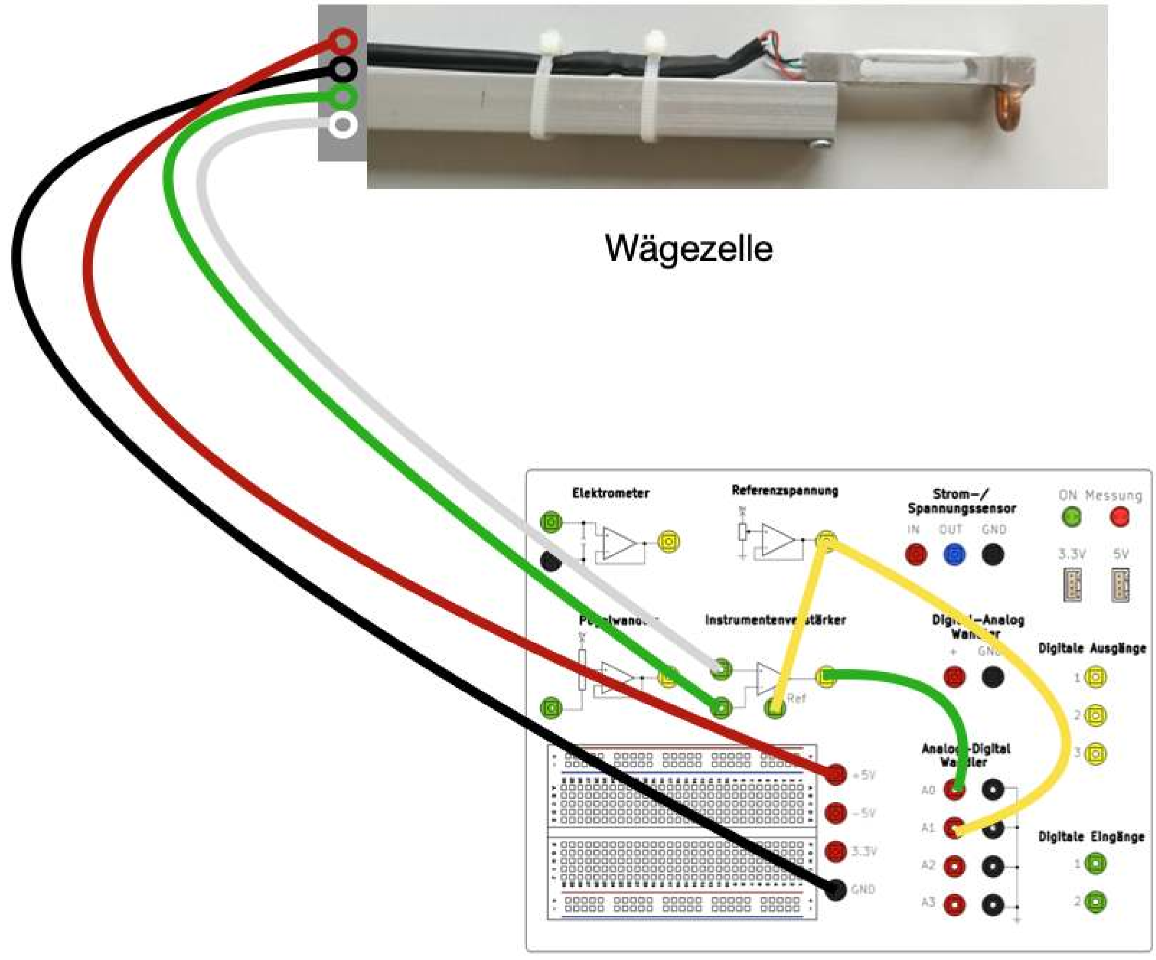
Fig. 36: **Charge spoon** Time curve of the voltage on the capacitor when approaching and touching a charged ball. At approx. 66 s the capacitor is grounded so that the voltage is 0 V. When the charged sphere approaches, the amount of voltage on the capacitor increases due to influence. When the ball touches the capacitor plate (t ≈ 67.9 s), the voltage reaches a constant value.



5.2 Force sensor

A force measurement is to be carried out using a load cell. It is checked whether the voltage applied to the load cell increases linearly with the attached mass, as expected.

The schematic structure is shown below:
Fig. 37: **force sensor** schematic structure



The load cell used can be rebuilt according to [these instructions](#).

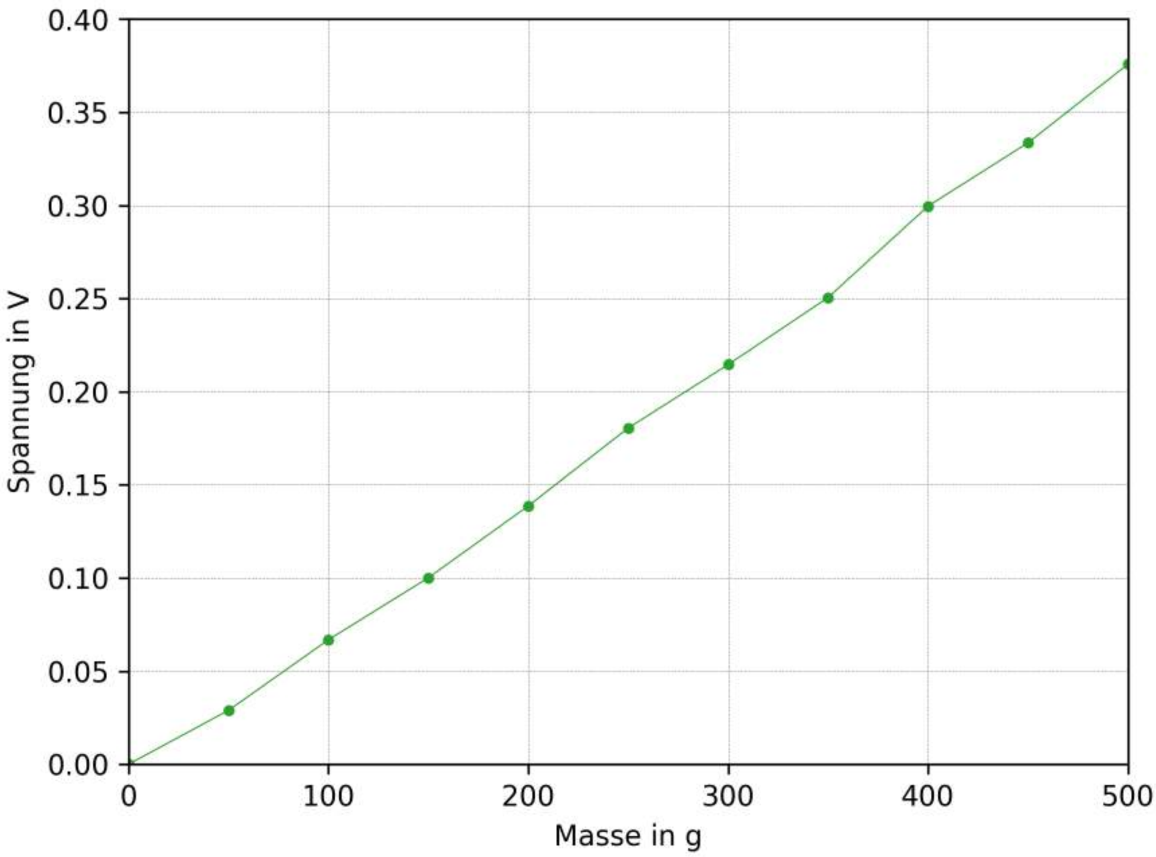
First, the load cell is supplied with an operating voltage of U=5V and screwed to a device so that weights can be attached to it. The voltage difference between the two outputs of the load cell is a measure of the applied force. Since this difference is typically in the mV range, the voltage is amplified using the instrumentation amplifier. The output of the instrumentation amplifier is connected to input A0 of the ADC. Since the necessary gain factor is unknown, it is initially set small and then increased during the measurement until the signal is in a suitable value range. Since the polarity of the voltage is also unknown, a reference voltage is tapped and connected to the associated connection of the instrumentation amplifier.

This shifts the output voltage by the value of the reference voltage so that negative voltages can be shifted to positive voltages. Approx. 2-3V can be used, whereby the exact value of the reference voltage is irrelevant, as this voltage is then subtracted again. To do this, the reference voltage is applied to input A1 of the ADC and A0 - A1 selected as the output.

Once the setup is complete, the measurement can be started and the amplification factor selected with different masses so that a voltage is visible. The gain factor here is A=18. While the measurement is in progress, pieces of weight up to 500 g are hung on the load cell in 50 g increments. In addition, the voltage is taken up if no mass is attached.
The measured values are then exported and the stresses are assigned to the

respective attached masses. By averaging the voltage values over time during the time when the respective piece of mass was attached, a voltage value can be assigned to each mass. This results in ten voltage values for the ten pieces of mass. It can be seen that the voltage is proportional to the attached mass. The voltage that is measured without an attached mass is subtracted from the other voltages as an offset voltage. After determining the compensation function, this load cell can be used as a scale for masses of up to 500 g.

Fig. 37: The voltage of the load cell increases with increasing force. The offset voltage that is applied without an attached mass is subtracted from the remaining voltage values. The measured values are compatible with a straight line through the origin.



The regression can either be carried out directly in *PhyPiDAQ* with the *ChanCalib* function, or the values are exported and then transferred to Excel, Python, etc. to be further processed.

Config:

kraftsensor.daq:

```
DeviceFile: config/kraft_ADS1115Config.yaml   # 16 bit ADC, I2C bus
ChanLabels: ['Spannung']             # names for channels
ChanUnits: ['V']         # units for channels
ChanColors: [darkblue]      # channel colours in display

Interval: 0.05                  # logging interval
NHistoryPoints: 20000           # number of points used in history buffer,
time=NHistoryPoints*Interval = 2000*0.05 = 100 seonds
DisplayModule: DataGraphs     # text, bar-graph, history and xy-view
Title: "Data from File"       # display title
DataFile:   null              #  null to disable
CSVseparator: '   '             # field separator, set to ';' for German Excel
```

kraft_ADS1115Config.yaml:

```
DAQModule: ADS1115Config
ADCChannels: [0]
DifModeChan: [true]
Gain: [1]
sampleRate: 860
```

5.3 Photo effect

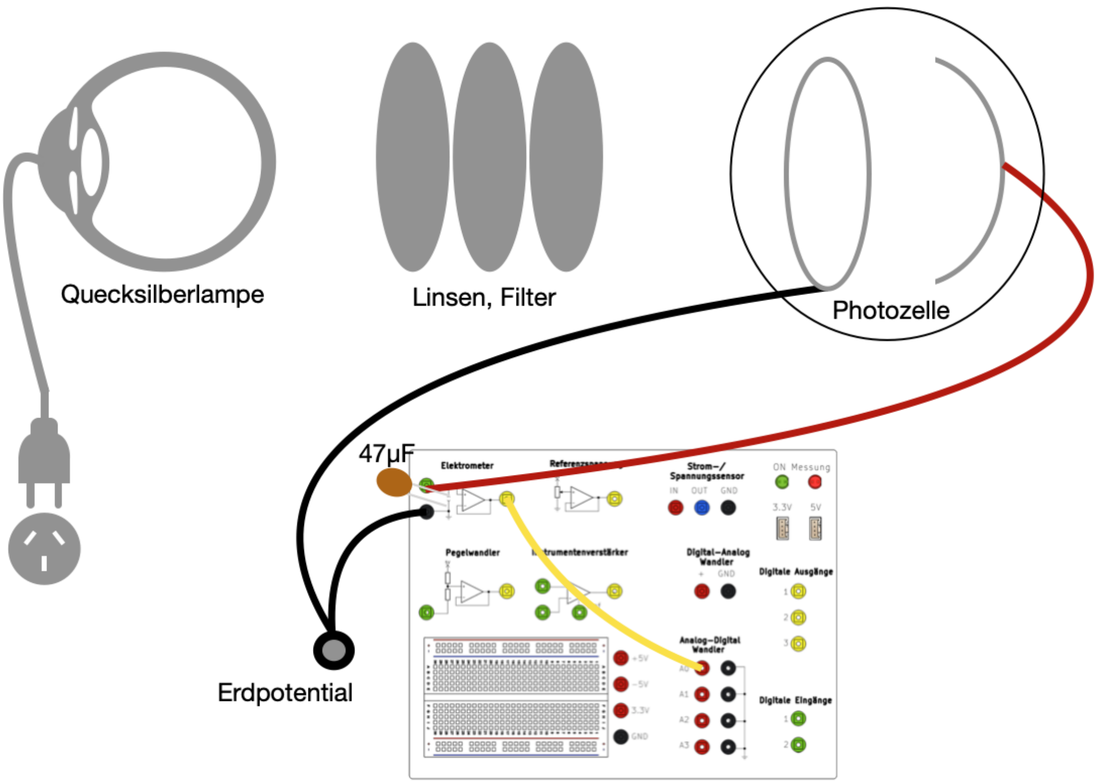
The photo effect is examined in more detail below. The resulting counter-voltage should be measured for six different wavelengths in the range from *λ = 360 nm* to λ=590 nm. Then the ratio *h/e*, where *h* is Planck's quantum and *e* is the elementary charge, should be determined.

A mercury lamp is used as the light source because it also emits light in the UV range. The light beam is bundled with lenses and reduced to the respective wavelength with interference filters. When the photons hit the cathode, electrons are released and a positive excess charge is created on the initially neutrally charged plate. If electrons hit the opposite anode, it is negatively charged. The separation of charges between the anode and the cathode creates an increasing electric field, which slows down further electrons that fly from the cathode to the anode. In equilibrium, the breaking force is so great that even electrons no longer arrive at the anode with maximum kinetic energy. The voltage between the cathode and anode is then maximum. The maximum voltage then corresponds to the counter voltage.

The measuring method used here contains a capacitor connected in parallel to the photocell, which is charged by the photovoltage. The tension that arises corresponds to the counter-tension. This method has the advantage that a rather complex and laborious setting of the photocurrent can be dispensed with. As a result, this test can be carried out in a very short time and with high accuracy.

On the hardware side, the voltage is measured with the electrometer, since a large internal resistance is required here in order not to falsify the measurement. A commercially available multimeter is therefore unsuitable. The circuit structure can be seen in the following figure:

Fig. 38: **Photoeffect** schematic structure



The capacitor with *C=47μF* may have to be adjusted if the charging is too fast or too slow.

The following config can be used in *PhyPiDAQ*. (The plots below were created by exporting the values from *PhyPiDAQ* as *.csv* and then reading them into a Python script. This can be done just as well for the intermediate level, for example, with an Excel table or something similar.)
photoeffekt.daq:

```
DeviceFile: config/photoeffekt_ADS1115Config.yaml   # 16 bit ADC, I2C bus
ChanLabels: ['Voltage']             # names for channels
ChanUnits: ['V']          # units for channels
ChanColors: [darkblue]      # channel colours in display

Interval: 0.05                 # logging interval
NHistoryPoints: 20000          # number of points used in history buffer,
time=NHistoryPoints*Interval = 2000*0.05 = 100 seonds
DisplayModule: DataGraphs      # text, bar-graph, history and xy-view
Title: "Data from File"        # display title
DataFile:   null               #  null to disable
CSVseparator: '   '             # field separator, set to ';' for German Excel
```

photoeffekt_ADS1115Config.yaml:

```
DAQModule: ADS1115Config
ADCChannels: [0]
DifModeChan: [false]
Gain: [1]
sampleRate: 860
```

The measurement can now be started and the counter voltage is displayed, which results from the charging of the capacitor by the photo effect. The capacitor is connected to ground again for discharging.

To calculate the ratio *h/e*, the energy balance is first drawn up. The incident light with the wavelength λ has the frequency $v=\lambda c$ and the energy $E_{light}=hv$. After deducting the work function, the released electrons have the kinetic energy $E_{kin}=E_{light}$-*E_A*. For the energy of the electric field, $E_{field}=Ue^*$ applies, where *U* is the counter voltage and *e* is the elementary charge. In the stationary case, the energy of the electric field is the same as the kinetic energy, $E_{field}=E_{kin}$, so that when inserted, $U \cdot e=hv-E\_A$ results. For the voltage *U*, $U=h/ev+eA$ applies. The ratio *h/e* corresponds to the slope in the *U-v* diagram in the figure below. The y-axis intercept corresponds to the work function *E_A*, with a negative sign indicating that this work has to be done. The deviation of $(h/e)_{measured}$ from the literature value of $h/e=4.14 \cdot 10^{(-15)}$ *Js/C* is 3.5%, which indicates a very precise measurement and the set goal of measuring in the percentage range fulfilled. The work function for a potassium cathode is *E_A = 2.25 eV*. The y-intercept corresponds to $|U| = 1.97V$. Since no other effects such as contact stresses are taken into account here, the determination of the work function with this method is basically only possible with greater uncertainties.
Although a detailed calculation is not carried out at this point and the y-axis intercept is extrapolated far away from the fitted measured values, the magnitude of the extrapolated work function still agrees well with the expected one. The photocurrent can also be calculated from the capacitor charge in the figure below. It can be seen that this is in the pico range. The current was smallest at 590 nm, which is evident from the relatively slow charging.

Fig. 39: **Photo effect** Charging of a capacitor on a vacuum photocell for different wavelengths of the incident light

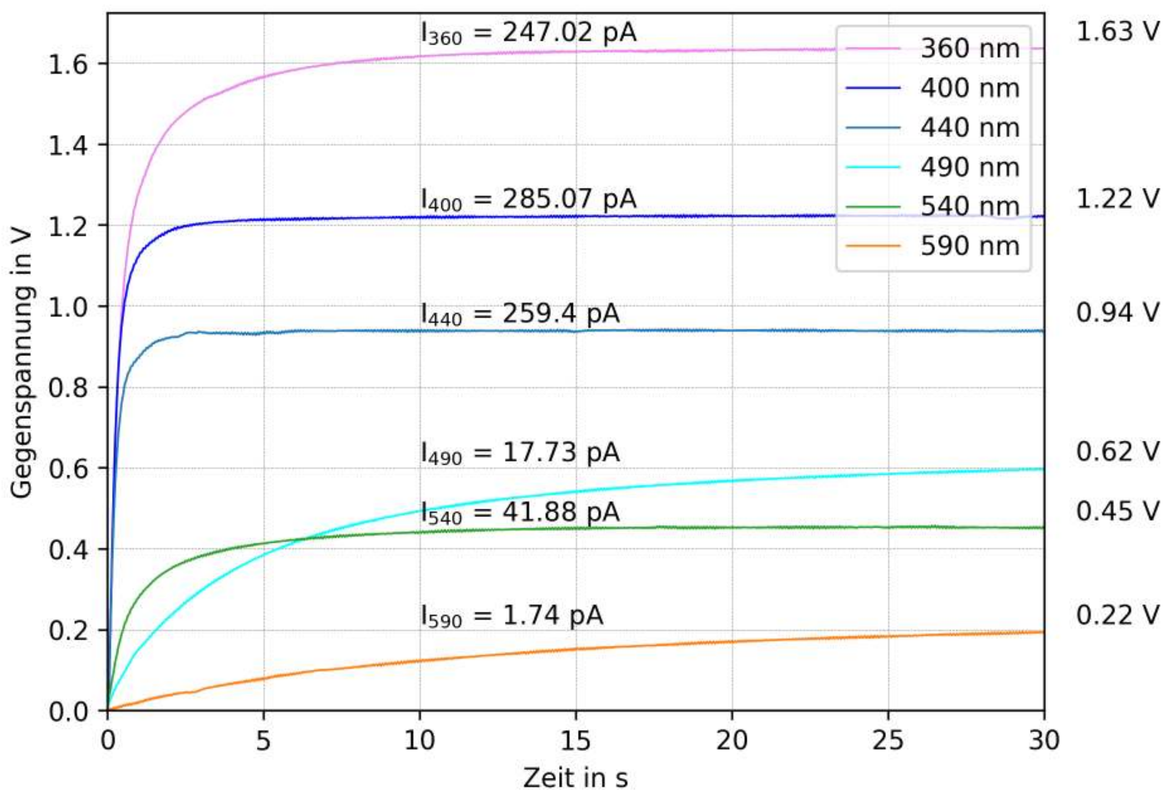


Fig. 40: **Photoeffect** Counter voltage versus frequency of light plotted with linear regression. The slope corresponds to the ratio *h/e*.