



Instructions for exercises

KM3NeT Masterclass 2026

Exercise 1 — Classification of events

Goal: To classify a set of real events recorded by KM3NeT, recognizing the topology of the signals collected by the optical modules.

*In the indicated web-site, you will find 10 movies and 10 sets of plots from real events acquired by the KM3NeT/ARCA telescope (in the configuration including 28 detection units). **You will need to match the movies with the corresponding plots and then, for each event, recognize which category it belongs to:***

Event class	Description
Upwardgoing muon	Nearly vertical track. The particle propagates from bottom to top. Likely sign of a neutrino that crossed the Earth before interacting inside or near the detector.
Downwardgoing muon	Nearly vertical but propagating from top to bottom: this could also be a neutrino, but it is more likely a muon arriving from the atmosphere toward the detector. The latter could be the result of a cosmic-ray interaction occurring in the atmosphere, which produces unstable mesons, such as pions and kaons, whose decays give rise to muons.
Horizontal muon	A horizontal muon is a muon that arrives nearly parallel to the ground, i.e., with an almost horizontal trajectory.
Shower / cascade	Signal distributed in a nearly spherical and localized form, without an extended track. This is the typical signal produced following interactions of electron- or tau-type neutrinos.
Non- classifiable event	Noisy, irregular signal, or one that cannot be attributed to any of the previous categories.

Take note for each event of your classification with a brief motivation. This will be useful for discussing the results.

Hint for visual analysis

Observe the temporal sequence of the detected photons (dark colors = early arrival, light colors = later arrival) and the spatial distribution of the signals on the detection units ("Detection Units" or DU) in the movies.

The direction of the track can be inferred by following the "wavefront" of light propagating through the detector.

Important: the plots indicate the vertical coordinate and the collection time for each signal measured on each DU.

Exercise 2 — Time calibration of detection units

Goal: To calibrate a set of detection units of the apparatus, determining the ideal values of time offsets.

1

Launch the program

Follow the instructions to open the URL on which to perform your analysis.

2

Upload the calibration file and execute the program

You can make a first check of the calibration by uploading the calibration file you have been provided (which is filled with null offsets).

3

Check the plots!

The “time residuals” for the set of detection units will be shown in the browser.

If the detector is well calibrated, these distributions will peak around the zero value. If the distributions are shifted, it means that the time offsets used are incorrect.

Modify the calibration.csv and reiterate

Based on the plots, modify the offset values in the calibration.csv file and run the calibration again. Repeat the process iteratively until all distributions are centered as close to zero as possible.

Tips:

- **Pay close attention** to which DUs are most poorly calibrated: start by correcting those first.
- **Save the different calibration attempts** with different filenames, so you can double-check the results later.
- **Write down the values** that work best on the provided sheet.
- **This exercise is tightly linked to the search of neutrino sources:** you might want to check the outcome of the source search after each calibration step

Important: The format of the .csv file must be maintained (otherwise the program will report an error during reading).

Warning: The calibration procedure is based on a comparison (the so-called ‘time residual plots’) between the signal acquisition times and the times they are expected, based on track reconstruction carried out using data collected from the other detection units surrounding the one being calibrated. It follows that **the calibration offsets are correlated** with one another and are not independent. (As a proof of this, you can check the effect by changing the offset of a single DU: then look at the time residual distributions of the other DUs). Consequently, it is highly recommended to complete this exercise in an iterative manner trying to estimate the DU offsets for all DUs each time.

Exercise 3 — Search for neutrino sources (Skymap)

Goal: To exploit the time calibration you have determined to look for neutrinos from cosmic sources.

1

Launch the program

Follow the instructions to open the URL on which to perform your search.

2

Upload your calibration file and do the search

The program will perform an analysis to recognize events associated to the positions of a set of four candidate neutrino sources in the sky.

3

Check the sky map and the level of significance of the sources

In the browser you will be shown a sky map indicating the directions of the reconstructed events and a zoom on the four candidate sources. The sources are to be identified by looking for an excess of events compared to the expected background.

Remark: the level of significance calculated for each source is clearly dependent on the quality of the calibration! You could compare what you get using the calibration files that you have determined at each step of the previous exercise.

And... **are you able to draw conclusions?** Are there sources for which you can claim a discovery?

Result sheet

<i>Exercise 1</i>	<i>Associated plots</i>	<i>Classification</i>	<i>Remarks</i>
<i>Event 1</i>			
<i>Event 2</i>			
<i>Event 3</i>			
<i>Event 4</i>			
<i>Event 5</i>			
<i>Event 6</i>			
<i>Event 7</i>			
<i>Event 8</i>			
<i>Event 9</i>			
<i>Event 10</i>			

Exercise 2 - Calibration	Name of file .csv	Iteration	Remarks
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	
		Iteration #__	

Exercise 3 - Skymap	Name of file .csv	Z_ML / Z_ON/FF	Remarks
		A: / B: / C: / D: /	
		A: / B: / C: / D: /	
		A: / B: / C: / D: /	
		A: / B: / C: / D: /	
		A: / B: / C: / D: /	
		A: / B: / C: / D: /	

***For any doubt or questions, don't hesitate to seek support!
Contact us at km3net-oc@km3net.de or check the instructions
at:
<https://www.km3net.org/education/masterclass-on-your-own/>***