Acquisition Lab

Introduction

This lab is intended to give an introduction on how to use the NSCL Data Acquisition (DAQ) system to collect data from the Modular Neutron Array (MoNA). In addition it will guide you through the process of analyzing those data using the NSCL analysis program (SpecTcl). It is assumed that you have already familiarized yourself with the scintillation process and the individual MoNA bars from the previous experiment.

Figure 1 Picture of MoNA bars without cabling

The first task is to learn how to use the analysis software, which is called “SpecTcl”. There are different versions of SpecTcl, specific for each type of experiment performed at the NSCL. Similarly, a special version of SpecTcl (SpecTcl_PAN) was made for the present experiment. This version of SpecTcl includes all the parameters you will need to use during your analysis. SpecTcl is used to read data, create spectra and study them. In the case of MoNA, as you have already seen in the oscilloscope experiment, the main parameters one needs to study are: time and charge. The signals you studied in the previous lab are fed into special electronics modules, they are transformed into digital signals and they are processed through sophisticated electronic circuits before showing up on your screen. In the end of this process, however, the important parameters are still the time and the collected charge. In SpecTcl, you will find complicated names for the different parameters, but once you know what they stand for, things are much easier. We use “TDC” to note the time parameters (TDC= Time to Digital Converter, and it’s the name of the module that does the time processing), For the charge parameters we use “QDC” for the same reason (QDC= Charge to Digital Converter). The actual names of the SpecTcl parameters are noted at the end of this document.

Before using these parameters for any application, you need to understand their physical meaning. The easiest one is the charge parameter (QDC). You have already learnt in the previous lab that the height of the pulses you studied in the oscilloscope depends on the amount of energy deposited in a MoNA bar and also on the position of the interaction. The corresponding electronics module transforms the collected charge into a digital signal. Since this charge signal depends on the deposited energy, we can calibrate it so that the charge parameters in your data are transformed into energy parameters. For the purpose of this experiment, all MoNA bars were energy calibrated in units of MeV[1].

Unlike the energy signals, the time signals of the individual MoNA photomultipliers (PMTs) are linked together. This way the time information of a PMT can be correlated to all others and time signals can be used to track particles going through several MoNA bars. To do that, we feed the pulses you studied in the oscilloscope lab into TDC modules. The digital outputs of all TDCs are imported in a special electronic circuit. This circuit uses the first signal that comes in as a trigger to open a time window of a few hundred ns[2] (red line in fig.2). Any other signal that arrives within this time window is recorded. If a signal comes after the time window, it's not recorded. At the end of this time window, all modules are cleared and they are ready to record the next interaction.

In fig.2 you can see that, the actual time quantity that is being recorded is the time between when a signal arrives and the end of the time window. So, when you look at your TDC parameter of a photomultiplier, the longest time corresponds to the "trigger signal" (t_a) and all other times (t_b, t_c) are shorter than that. This means that the recorded times are always relative to the trigger signal, which is not fixed. In fact, the trigger signal can come from any MoNA bar, the first one that gets hit. In order to get useful information out of the recorded times you need to combine the time parameters of two photomultipliers, e.g. the difference in the timing of the left and right photomultipliers in a MoNA bar relates to the position of interaction, similarl to what you have seen in the oscilloscope experiment.

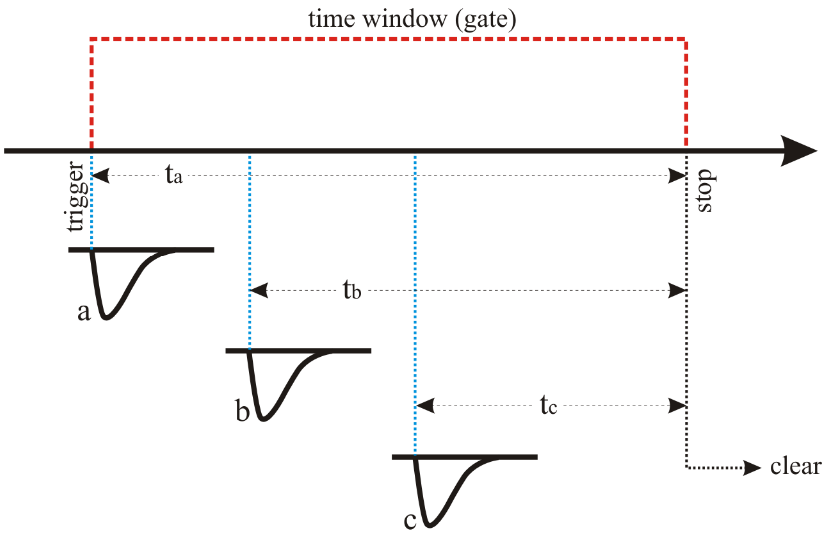

Figure 2: Trigger and timing of MoNA signals

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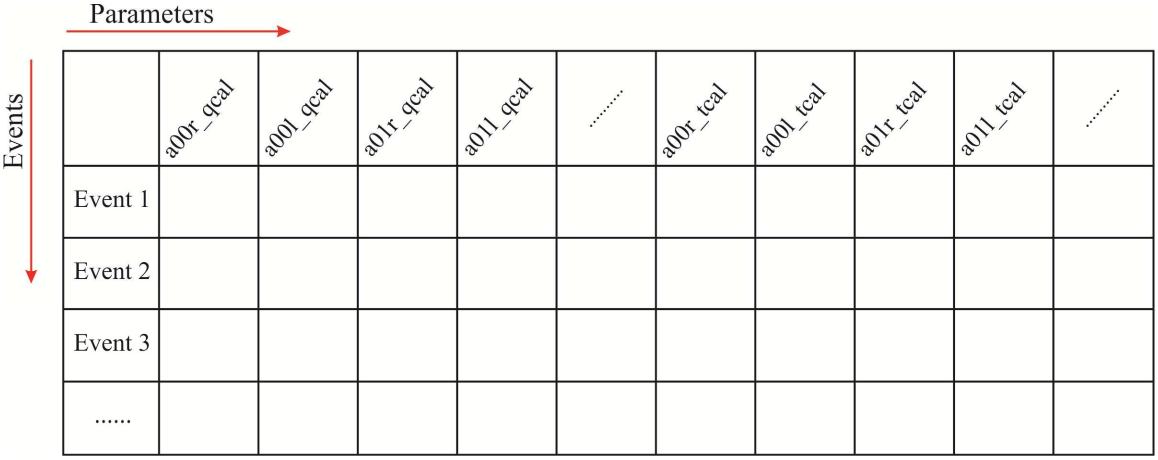
[1] MeV= Mega electron-Volt= 10^6 electron-Volt (eV). 1 eV is the amount of energy gained when an electron is accelerated through a potential difference of 1Volt. This is a standard unit used in nuclear physics for the energy of particles and gamma-rays.

[2] ns = nanoseconds = 10^{-9} s

The next thing you need to know before continuing with your experiment is how data are saved. This is important to understand how we can create meaningful new parameters from the initial time and energy ones. The data acquisition process we use here is called “event-by-event”. You can imagine one event as the red line in fig.2. All signals recorded during that time window belong to the same event. When you write data with multiple events it is similar to filling the rows of an array, where each row corresponds to one event. A simplified picture of the event-by-event concept is shown in fig.3. The different parameters are stored in the events like different columns in an array. So, in the example of fig.3 you can see the QDC and TDC parameters of bars A0 and A1, both for the left (L) and the right (R) photomultipliers.

The importance of collecting data event-by-event is that you can apply mathematical calculations to the parameters you are using. For example, we could take the average time between the left and right photomultipliers of the same bar (this parameter exists and it’s called “Tmean”). This would be like creating an additional column in the table of fig.3, with the name Tmean, and the contents of this column would be (TDC_left+TDC_right)/2. As you will see in the following, we can create useful new parameters (called “pseudo-parameters”) using the existing time and energy parameters of each photomultiplier.



	a00r_qcal	a00l_qcal	a01r_qcal	a01l_qcal	....	a00r_tcal	a00l_tcal	a01r_tcal	a01l_tcal	....
Event 1										
Event 2										
Event 3										
......										

Figure 3: Simplified picture of the event-by-event data collection

Before starting with the activities of this experiment, you will find a description of the analysis program, “*SpecTcl*”. Read through the introduction to see what this program can do. You don’t need to remember everything; later, when you are following the activity worksheet there are specific instructions about which of the given buttons to use and you can go back and read at any time.

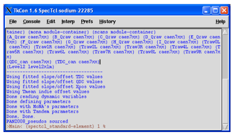
The first step is to learn some basic functions of SpecTcl like creating spectra, filling them with data and looking at them. You will start with an existing cosmic ray run and you will study the time and energy signals. Once you know how to use SpecTcl you will repeat the oscilloscope experiment from a different point of view. When you place a source at different positions next to a MoNA bar, instead of looking at the signals in the oscilloscope, you will study the corresponding spectra. In addition you will also look at spectra without any radiation sources around, where you will be able to detect and study cosmic rays. This document will guide you through the different steps of the standard analysis procedure one needs to follow when dealing with complicated setups such as MoNA.

Introduction to Spectcl

To open Spectcl, click on the icon on the desktop that says “SpecTcl_PAN” When Spectcl is opened, you will see four windows: Xamine, TkCon, Spectcl Control and TreeParameter GUI. Read the following descriptions of each window. You will familiarize yourself with each window more as you follow this worksheet, and you can refer to the button descriptions as you work with each window. Under each window description is an explanation of each of the buttons. *The ones you should read prior to starting the worksheet are noted with an asterisk.* The rest are available for reference as you may need them later on.

Note: All words in italics in this experiment refer to vocabulary mentioned in this introduction. If it is not in italics then it does not show up in one of these four windows. Also, all parameters with their descriptions are at the end of this document.

- The **TkCon** window is used for creating new parameters, spectra, and gates, for applying gates to existing spectra and anything else you might need. To use this window, an understanding of tcl programming is needed; therefore, buttons have been created for you in the following two windows to minimize your need to use the TkCon window.



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tainer} {mona module-container} {ncans module-container}
{A_Qraw caen7xx} {B_Qraw caen7xx} {C_Qraw caen7xx} {D_Qraw caen7xx} {E_Qraw caen
7xx} {F_Qraw caen7xx} {G_Qraw caen7xx} {H_Qraw caen7xx} {I_Qraw caen7xx} {Traw0L
 caen7xx} {Traw1R caen7xx} {Traw2L caen7xx} {Traw3R caen7xx} {Traw4L caen7xx} {T
raw5R caen7xx} {Traw6L caen7xx} {Traw7R caen7xx} {Traw8L caen7xx} {Traw9R caen7x
x}
{QDC_can caen7xx} {TDC_can caen7xx}
{Level2 level2xlm}
-----------------------------------
Using fitted slope/offset TDC values
Using fitted slope/offset QDC values
Using fitted slope/offset Xpos values
Using Tmean indie offset values
Done reading dynamic variables
Done defining parameters
Done with MoNA's parameters
Done with Tandem parameters
Done, Done.
PAN2008_pseudos sourced
>Main< (spectcl_standard-element) 1 %
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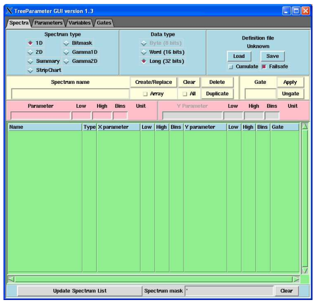
- The **TreeParameter GUI** (or “**Tree GUI**” or “**GUI**”) is available to see spectra, parameters, variables, and gates (see tabs at the top). You will use the Spectra and Gates tabs. Utilizing this window is easier than using the programming language in the TkCon window but either will accomplish the same goals.



  **Load*: Choose this button to load saved files. The files you can load here should contain definitions of spectra, variables and gates. When you first start you will not have any files to load. In the process of the experiment, if you decide to save your definitions (see “*save*” button), you can load them back using this button.

  **Save*: To save the spectra you have created along with all gates, click this button and give your file a name. This only saves the spectrum definition and its contents. There is a different button in the Xamine window to save the spectrum itself.

  **Spectrum Type*: A spectrum is a histogram of the *parameter* (see definition on the next page) chosen and the *bins* are the columns of the histogram. Here, the only two types of spectra you will make are *1D* and *2D spectra*. A *1D spectrum* has the parameter on the x-axis (horizontal axis) and the number of counts on the y-axis (vertical axis). A *2D spectrum* is used to plot 2 parameters against each other. The first parameter is displayed as x-axis, the second as y-axis and the counts appear as a z-axis which is illustrated by the color code.

  **Spectrum Name*: You can name the spectrum anything you would like, but try to make it easy enough to remember.

**Create/Replace*: Click this button to create your spectrum. If you change the details of a spectrum and keep the same name, you will replace the old by clicking this button. You should click on this button only when you have filled all necessary fields (spectrum title, low and high limits, bins).

Clear: This button clears the contents of a spectrum but keeps it's definition. This means that your spectrum will still exist but it will have zero counts.

Delete: Delete any spectra by highlighting them (you can highlight multiple spectra in the table using the "Shift" or "Ctrl" keys) and then press this button.

Duplicate: Click on the spectra you would like to duplicate and then click this button to create the identical spectra to the originals. The new spectra are given new names, but the *parameter, low, high* and *bins* stay the same as the originals.

Gate: A gate is a selection of events that satisfy specific conditions. Looking at the event-by-event table in fig.2, an example of a gate would be to ask for events that have certain parameter between two limits. Applying a gate to a spectrum means that you only see events that satisfy the condition of this gate. This button is used to apply a gate to a selected spectrum (for information on how to create a gate , see later "cut" and "contour"). Highlight the spectra you desire to gate, enter in the gate name or find it by clicking on *Gate* and apply it by clicking on *Apply*. To ungate spectra, highlight them and click *Ungate*.

**Parameter*: A list of parameters are at the end of this packet so you can understand what each one means. There are two types of parameters: raw and pseudo. The *raw parameters* collect information directly from data received in the MoNA bars. *Pseudo parameters* operate on the raw parameters in some way. Both are very useful.

**Low*: The number you put in here sets the low end of the range of what your spectrum will show in the Xamine window (see page #4).

**High*: The number you put in here sets the high end of the range.

**Bins*: This sets the number of columns your spectrum has. For example, if the range is 0-99 and you have 10 bins, then all of the data between 0 and 9 will be lumped together and will be considered the same and appear in the same bin. Also, the data between 10-19, 20-29, etc. will be lumped together. This clearly would be too few bins because the data would not be distinct enough. On the other hand, if you choose too many bins (e.g. for a total of 100 counts you choose to plot your spectrum with 10000 bins) then you end up with too few counts per bin (in our example 1 or 0) and then it's hard to observe any useful structure in your spectrum.

Y Parameter: The Y Parameter section is utilized for *2D spectra*. It operates the same as the *X Parameter* with the *low, high* and *bins,* but this parameter shows up on the y-axis in Xamine.

- The **SpecTcl Control GUI** window (or "**Control**" window) is used to find parameters you might need, create pseudo spectra, and sort the data you would like to run.

Run: 0 Analyzed Buffers: 0 Buffers/sec: 0

Source: none

**Start Analysis*: You only need to press this button after stopping a run. Clicking on *Attach to File* (see below) will start analyzing the data initially. Once you have a run being read in, this button becomes *Stop Analysis* and you can use it to stop the reading.

**Clear Spectra*: This button is extremely important. Click on this to clear the data you have run. You want to do this every time you change a spectrum (which is done in the Tree GUI) or when you start a new run.

Help

Exit*: Click this button to close Spectcl. **Be sure to save the spectra in the Tree GUI before exiting the program.

**Energy Spectra*. Clicking on this button will create the calibrated energy spectra (QDC) for all 288 photomultipliers of MoNA. You can see a list of the created spectra in the “Tree Parameter GUI”.

**Time Spectra*. Clicking on this button will create the calibrated time spectra (TDC) for all 288 photomultipliers of MoNA. You can see a list of the created spectra in the “Tree Parameter GUI”.

**Qmean spectra*. This button will create for all 144 MoNA bars, spectra that correspond to the pseudo parameters Qmean. This parameter corresponds to the average of the energy signals of the left and right side of a MoNA bar.

**Tmean spectra*. This button will create for all 144 MoNA bars, spectra that correspond to the pseudo parameters Tmean. This parameter corresponds to the average of the time signals of the left and right side of a MoNA bar.

**Xpos spectra*. This button will create for all 144 MoNA bars, spectra that correspond to the pseudo parameters Xpos. This parameter gives the position of interaction along the x-axis of a MoNA bar.

**Time of flight*: This button creates all Tdiff_...15-...0 spectra which have parameters Tdiff_...15-...0. See a list of parameters at the end of this document.

**X position difference*: This button creates all Xdiff_...15-...0 spectra.

**Left-Right Q diff*: This button creates all Qdiff_...LR spectra.

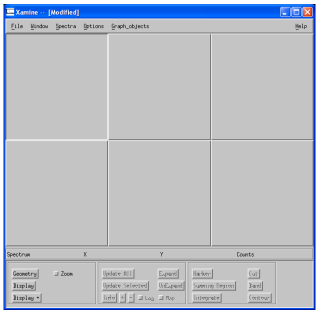
**Left-Right time diff*: This button creates all Tdiff_...LR spectra.

**Center of Gravity*: This button creates all COG_... spectra.

**Attach to File*: Click on this button to source data that has already been collected. When you click on this button an additional window appears with a list of directories. Choose the “Complete” directory to see previous runs and choose the run you want to read.

Save: Use this button to save the data for a specific spectrum and to be able to use the data in excel. How to use this button is explained in the section 8.g.

Read: Use this button to read the files that you have saved using the "*Save*" button.



- The **Xamine** window is where spectra are displayed and where data analysis occurs. The spectra that show up can be analyzed by using the various buttons.

  **Geometry*: This allows for multiple spectra to show up. The number of spectra is determined by the number of rows and columns you choose. For example, a 2 x 3 geometry will have 6 spectra as shown in Figure #5.

  **Display*: Click this button to choose the spectrum you want to show.

  **Display +*: Click this button if you want to display multiple spectra quickly.

  **Update All*: This button updates all of the spectra with the data received.

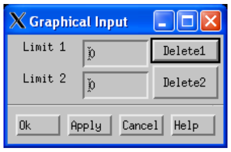
  Update Selected: This button updates only the spectrum selected.

  Info: This button displays various technical information.

  +/-: These buttons allow you to change the y-axis either by getting a closer look (+) or looking at it from a distance (-).

  Log: This button displays the spectra with a logarithmic scale.

  Map: This button changes the units in the horizontal axis from physical ones (ns for time, MeV for energy, etc) to bin numbers.



Limit 1 0

Limit 2 0

  **Expand*: Choose this button to show a certain region. Only the spectrum that is between the two points you choose will be displayed. You pick the limits by mouse clicks or by entering in low and high x values in the popup window.

  Unexpand: This button will undo the *Expand* command applied earlier.

  Marker: This button puts a mark on the spectrum and is used to put a pointer somewhere in a spectrum to compare it to the next run. The marker is not cleared when you clear the spectrum.

  Summing Region: Use this button if you want to know the centroid of the data, the Full Width at Half Maximum (FWHM) or the number of counts within a certain region. You can define the region you want (same procedure as *Expand*), and the *Integrate* button will give you an analysis of the data within the summing region you chose.

  Cut: This button allows you to make a *slice gate*. A slice gate is a 1D gate that allows you to keep the data within the gate and get rid of the data outside of the gate. That way you can look at only the data you want to see for any spectra the gate is applied to. To create a slice gate use the same procedure as mentioned for the *Expand* button.

Band: A band is similar to the marker but it's used to mark a line or a region and not just a point.

Contour: This button allows you to make a *contour gate*. A contour gate is a 2D gate that allows you to keep the data within the gate and get rid of the data outside of the gate. To create contour gate either click around the region that you desire, or enter in the x and y coordinates for each point of the contour in the pop-up window.

Note: When you create a gate it's like setting a condition that needs to be fulfilled. However, just creating the gate does not have any effect whatsoever. You need to apply it on specific spectra in order for it to have some effect.

Activity Worksheet

General

You will start with learning how to create your own spectra and explore Spectcl. Be sure to explore the meaning of what you are doing and not just follow the steps we have provided so that you can really understand it and apply it later on. The following instructions will guide you through the process. The data files you will be reading are long. You don't have to wait for the file to end. When you are done with your analysis you can proceed to the next step.

To login to your computers use the following (case sensitive):

Username: pan11

Password: Neutrons10

On your screen you can see different buttons. To start SpecTcl you need to click on the icon "SpecTcl_PAN". Four windows should appear in your screen. If you haven't done so, you should read the "*Introduction to SpecTcl*" section in page 5. Here you can follow some step-by-step instructions on how to use SpecTcl create spectra and analyze them.

1) You can start by creating some **energy spectra**. To do that you have to click on the "*Energy Spectra*" button on the top left corner of the "*SpecTcl Control*" window.

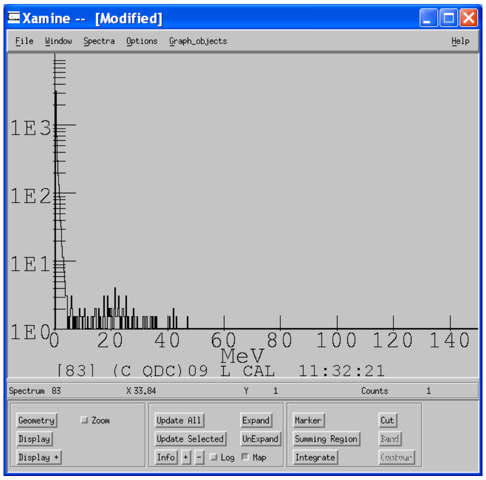
    a) To see that the spectra were created correctly you can go to the "*Tree Parameter GUI*", in the tab called "*Spectra*" and check if you can see a long list of spectra called "…._qcal", where instead of "…." you'll see bar names and L or R for left of right photomultiplier respectively (see last page for details on parameter names). "qcal" stands for calibrated QDC spectrum.

    b) If your spectra are not there call the support staff for help.

    c) Once the spectra are created, it is necessary to fill them with data and plot them. Later you will collect new data and use them to fill your spectra. For now, in order to learn how spectcl works you will use some existing cosmic ray data. To read the existing data file go to the "*SpecTcl Control*" window and click on the "*Attach to file*" button at the bottom. A new window appears with a list of directories. Open the "complete" directory. Choose file run66-run4096.evt and click "*Open*". Immediately, at the bottom of this window you should see the "*Run"* number to be set at "16" and the *"Analyzed buffers*" to be increasing.

    d) Now that you have some data being read in, you can look at some spectra. To do that go to the "*Xamine*" window and click on the button "*Display*" at the bottom left corner. This will open a new window that contains the list of spectra created so far. So this list should have 288 energy spectra ...._qcal. Choose a spectrum (e.g for bar E5, right side you would choose e05r_qcal), and then click "ok". At this point you can choose to look at the spectrum of any MoNA bar you want because all of them are affected by cosmic rays the same way.

e) In the "*Xamine*" window you have your first spectrum, which should look like the picture to the right. If you wait long enough you will see that a nice peak will be formed in the region around 20 MeV.



Spectrum 83 X 33.84 Y 1 Counts 1

f) While you are waiting for more events, discuss within your group and try to answer the following questions. Discuss your answers with the support staff.

   i) What do the horizontal axis (x-axis) and the vertical axis (y-axis) correspond to?

   ii) The spectrum you are looking at is in fact a histogram and the bars of the histogram are called "bins". Assume that you have a bin that starts at energy= 12.0 MeV and stops at 12.1 MeV and the number of counts in this bin is 10. Explain what this means in terms of physical quantities (particles, energy, interactions, etc).

   iii) Cosmic ray muons are highly energetic particles. Traveling through a MoNA bar, they deposit energy equal to ~20 MeV. Can you show which part of your spectrum corresponds to the interaction with muons? What does the rest of the spectrum consist of?

   Tip: to zoom in on a section of your spectrum, use the *Expand* button in the Xamine window, which is explained in the introduction.

g) Once you understand what your spectrum presents, it's time to learn how to change it. Go to the "*Tree Parameter GUI*", in the "*Spectra*" tab. Find the spectrum you were looking at. Double click on it (don't worry about the warning message, just click ok). When you double-click on the spectrum you should see the information of the spectrum show up in the white and pink regions of the window (title, parameter, low and high limits, bins).

h) The bins number of your spectrum is set to 3000. Change this number to 30 and click on the button "*Create/Replace*". Record what you think the spectra will look like in your logbook.

Note: when you replace an existing spectrum, it might disappear from the Xamine window. If this is the case, you just need to reload it using the "Display" button.

i) Clear the spectra using the “*Clear* Spectra” button in the control window. Repeat steps 1c) and 1d) choosing the same bar and look at your spectrum in the “*Xamine*” window. Does your spectrum look like what you expected? Compare this spectrum with the previous one and explain what the differences are.

Note: remember that before attaching to file to look at new data you need to clear the existing spectra using the button “*Clear Spectra*” in the “*SpecTcl Control*” window.

j) If you changed the bins number to 300000 can you imagine what the spectrum would look like?

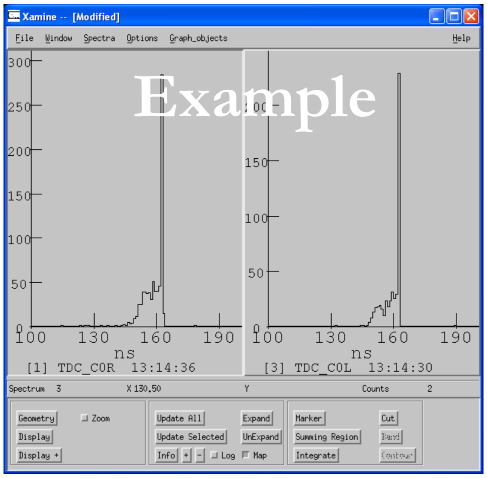
k) The other part of the spectrum that can be changed is the scale of the vertical axis. It can be either linear or logarithmic. Most spectra appear in log scale by default. You can change that by clicking on the “*Log*” button at the bottom of the “*Xamine*” window.

l) You can also change the limits of your horizontal axis. You can do that in a similar way as changing the binning number. In the “*Tree Parameter GUI*” window, in the pink region, you can set the low and high limit of your spectrum. When you change the value in any of these boxes click on the “*Create/Replace*” button. Change the limits of your spectrum so that you can focus on the low energy peak and not see the muon signal. Look at the spectrum in Xamine. Is this what you expected to see?

2) **Time Spectra.** In order to create time spectra you have to go in the “*SpecTcl Control*” window and click on the “*Time Spectra*” button. This button behaves the same way as the “*Energy Spectra*” button so you will basically follow the same procedure as in step 1).

a) To look at the time spectra in Xamine you have to use the “*Display*” button and choose a spectrum that corresponds to “TDC”, which ends in tcal. The names “..._tcal” are used in a similar way as the QDC ones (see last page of this document for details on the parameter names).

b) First clear the spectra using the button “*Clear* Spectra” in the “*SpecTcl Control*” window. Then use the “*Attach to File*” button similarly as in step 1) to load file run66-4096.evt



Spectrum 3 X 130.50 Y Counts 2

c) As a new exercise, you can look at 2 time spectra at the same time. To do that click on “*Geometry*” and choose a 1 x 2 set up. Then, click the *Display+* button and double click on the spectrum you would like to display. Do this for the next spectrum and then click *Cancel*. All time spectra should look approximately the same so for now it doesn't matter which two spectra you choose to look at.

Tip: to view just one of the spectra double click the one you want or click on "*Zoom*" in the Xamine window.

d) In your Xamine window you should have two spectra that look like the picture in page 12. Note that the spectra in the picture are in linear scale. Your spectra are by default in logarithmic scale. Use the "*Log*" button in Xamine to change to linear scale.

e) Note the binning and the low and high limits of your spectrum. If they are much different from the picture above change them and look at the same spectra again.

f) In your spectra the horizontal axis is time. Time is not an absolute quantity. We are always measuring time relative to a starting point. In order to understand how time is measured for MoNA discuss within your group and try to give answers to the following questions:

   i) First go back to the introduction part of this document and read the part related to figure 2. Using figure 2 as a qualitative guide, write in your logbook which of the three signals (a, b, c) shown in this figure was the first one to arrive in MoNA. Which of the signals will show up in your spectra as having the shortest time?

   ii) You have to realize that figure 2 shows 3 time signals coming from 3 different MoNA bars, within a single event. On the other hand, the spectrum you see in your screen shows the time signals in the same MoNA bar for a large number of different events. So, in some events the bar you are looking at was in fact the trigger signal (signal "a" in fig.2), and in other events it was not. Write in your logbook which part of your spectrum corresponds to the events where your bar was the trigger.

   iii) If the bar you are looking at was not the trigger it means that a different bar was the trigger. In this case, do you expect to see shorter or longer times in your spectrum?

   iv) Can you imagine what the time spectrum would look like if your bar were set such as it was always the trigger? How would the other spectra look like?

   v) Discuss your answers with the support staff.

3) Next, you will look at the **average energy spectra**. The parameter associated with the average energy spectrum is "Qmean_...". This parameter is calculated from the energies of the left and right PMT in the same bar as follows:

Qmean = (QDC_left + QDC_right)*0.5

a) Record in your log book what you think the difference is between QDC and Qmean parameters. Do not worry about being right or wrong at this point.

b) To create the Qmean spectra for all MoNA bars click on the "*Qmean* Spectra" button in the "*SpecTcl Control*" window.

c) Clear the previous data and "*Attach to File*" again to read file run66-4096.evt from the "complete" directory. Display your spectrum in Xamine. In order to compare the Qmean spectrum with the QDC spectra, create 3x1 geometry in Xamine. Choose a bar and display the left and right QDC spectra of this bar and also the Qmean spectrum of the same bar.

d) If necessary change the high, low and bins in the "*Parameter Tree GUI*", clear spectra, collect new data and redisplay the spectra in Xamine. Remember to set the same low and high limits and the same bins for all three spectra otherwise the comparison will be harder. Draw the finalized spectra in your logbook, and explain what you see.

e) Is the Qmean spectrum different from the QDC one? Explain why.

f) Usually we are not interested in all events that appear in our spectra but only in a part of them. For this reason it is necessary to be able to select only the spectra we are interested in. In this part of the experiment let's assume that you are interested in the cosmic rays. Looking at your Qmean spectrum you should be able to identify which part of the spectrum corresponds to the cosmic ray muons and what the rest of the spectrum is.

g) To select just the muons and to get rid of all of the background data, you need to create a *slice gate* (see description of gates at the beginning for more information). The purpose of the slice gate is to only show data within two limits. To create a slice gate, go in the Xamine window and click *Cut.* This will open a new window where you can type the upper and lower limits of you gate and also a name for it. Alternatively, you can set the gate limits by clicking in the spectrum. The first will set the lower limit and the second click the higher limit. Here you should set your gate such as to select only the cosmic ray muons.

h) To view the gate you just created, go into the Tree GUI and click on the "*Gate*" tab at the top. Click *Update Gate List* and you should see the gate in the table.

i) To apply the gate, go back to the "*Spectra*" tab in the "*Parameter Tree GUI*" and highlight the spectrum you want to gate. At this point select the "…_qmean" spectrum you were looking at. You can either find your gate by clicking "*Gate*" or enter in the name of the gate in the space below the word *Gate*. Then click *Apply*, and you should see it show up in the last column in the table in the GUI beside the spectrum you chose.

j) Clear the spectra in the Control window and attach to the same file. Did the gate work as expected?

k) Record the gate name, type, range and also draw the new, gated spectrum in your logbook.

l) Ask the support staff to review your work before moving on.

Source measurements

Now that you know how to use SpecTcl to create and display spectra and also to create and apply gates you are ready to proceed with a real experiment. The idea is similar to the oscilloscope experiment: you need to be able to find the position of a signal in a MoNA bar using the time and/or energy parameters of the two photomultipliers. You have already learned that you can use the existing parameters to create new ones (called "pseudo parameters"). There are many pseudo-parameters already created for you. Before you proceed with the experiment, discuss within your group, which are the possible parameters that would be useful for you.

You have already seen in the oscilloscope experiment that you can use the time difference of the left and right PMTs of the same bar to find the position of the interaction along the bar. You also found that you could do the same thing with the energy signal (height of your pulse) using the "Center of Gravity" parameter. In this experiment you will repeat the previous experiment but instead of looking at the signals in the oscilloscope you will use the corresponding parameters.

Measurements

4) Before starting the data collection you first need to create some spectra in order to be able to look at the online data. You will look at the same quantities you studied in the oscilloscope experiment, which were (Tl-Tr), (Pl-Pr) and (Pl-Pr)/(Pl+Pr). Here instead of the symbol "P" we use the symbol "Q", but it refers to the same quantity.

   a) In order to create the relevant spectra you need to follow the procedure you learnt earlier in this experiment. The parameters you will need have the following names:

      Tdiff_**LR = (Tl-Tr)

      Qdiff_**LR = (Pl-Pr)

      COG_** = (Pl-Pr)/(Pl+Pr)

      where in the place of ** you need to put the name of your bar (e.g. A0).

      To create the spectra for the above parameters you can use the buttons in the "*SpecTcl* Control" window:

      - Left-Right Qdiff
      - Left-Right time diff
      - Center of gravity

      These buttons will create the 1D spectra of the three parameters mentioned above for all 144 MoNA bars. The "*Center of Gravity*" button will also create 2D spectra where x = Tdiff_**LR and y = COG_**. The name of this type of spectra is **_Tdiff_COG.

b) Which bar did you use in the oscilloscope experiment? If you don't know ask the support staff. You will be looking at spectra from this bar.

c) Create 2x2 geometry in Xamine. Use the "*Display+*" button to present the four spectra that correspond to your bar (Tdiff_**LR, Qdiff_**LR, COG_**, **_Tdiff_COG).

d) The support staff will run the acquisition program to collect data for you. Before starting, one person from each group should accompany the support staff in the experimental area and check where the source was placed with respect to the bar you are studying. Then come back in the analysis area and write in your logbook your bar and the position of the source. The support staff should tell you what the run number is. Note that in your logbook too. This procedure should be repeated for at least 5 different positions.

e) You can look at your different spectra while you are taking data. To do that click on the "*Attach to file*" button in the Control Window and open the "current" directory where you will find the current run file. Later when the collection of data is stopped, this file will be moved automatically into the "complete" directory and you can attach to it if you want to continue your analysis.

f) You can start with some "online" analysis during the data collection time but the main part of you analysis will be done when all five runs are recorded. First you should do a qualitative study of your four spectra and discuss with your group members the significance of each. Change the high and low limit of your spectra and also their binning if you think it is needed.

g) Once you understand what each spectrum shows you can start the calibration procedure. Similarly to what you did in the oscilloscope experiment, you need to fill the table shown below. The table includes the same quantities you used in the first experiment (Tl-Tr, Pl-Pr and COG). In addition next to each of these columns you will find a column marked as σ(***). This symbol corresponds to the error or uncertainty of your measurement. Every measurement has some uncertainty, even the most accurate ones. So, it is very important, together with the measured value of a quantity, to also determine its error.

There are multiple ways to find the center (centroid) of your peak. The simplest one is by placing the cursor over what seems to be the peak and looking at the x value below the spectrum. A different way is to ask SpecTcl to fit your distribution and give you the centroid of this fit. To do that you need to go in Xamine and click on the "*Summing region*" button at the bottom. You can set the upper and lower limits of the region of interest by clicking on the spectrum. Remember to set these limits symmetrically around your peak. When you set the

Table 1

Run No	x	(Tl-Tr)	σ(Tl-Tr)	(Pl-Pr)	σ(Pl-Pr)	COG	σ(COG)

limits you click "*Ok*". To have SpecTcl perform the fit and give you the results you need to click on the "*Integrate*" button in Xamine. A new window shows up with the information you need:

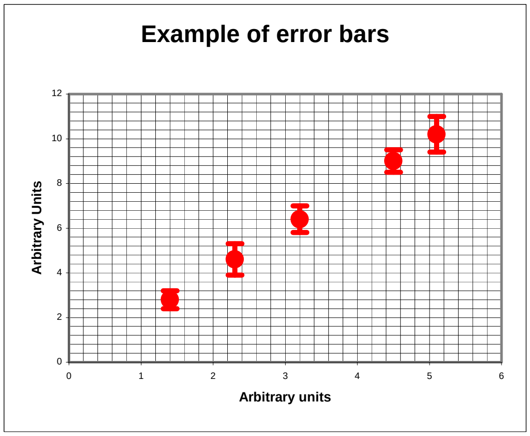
- Centroid: the center of the distribution
- FWHM: Full Width at Half Maximum is the width of the distribution at a height that is half of the maximum height. This is a criterion used to check the width of a distribution.
- Area: The total number of counts inside the limits of your region of interest.

Using the above information you can estimate the error of your centroid value using the formula:

$$\sigma = \frac{\text{FWHM}}{\sqrt{\text{Area}}}$$

Perform this analysis and fill in the different columns of Table 1.

h) When you are done with your spectra analysis, you have to make two graphs. These are the same graphs you did in the oscilloscope experiment where the horizontal axis is the position of the source and the vertical axis is (Tl-Tr) for the first graph and COG for the second. Together with the actual values of your measurements, draw also the errors. The figure to the right does not correspond to any physical quantities but it shows how to draw the error bars on your plot. The figure shows error bars only on the vertical axis but you could do the same thing for the horizontal axis as well.



i) In you opinion, which of the two

graphs would help you determine the position of an event more accurately?

  ii) Compared to the previous experiment, which of the two methods would you choose for your calibration and why?

i) The support staff will, once again, place the source at a new location of their choice, but unknown to you. Clear the spectra collect data and use what you have found so far to try to determine where the source is located. Once you have come to a conclusion, ask the support staff where your source is. How close were you? Was your estimation better or worse than the previous experiment?

Important: For the second part of this experiment you will need to analyze cosmic ray data. To have enough statistics you will need to collect data overnight. Before leaving on the first day you need to ask the support staff if they started the cosmic ray run and note the run number in your logbook.

Cosmic ray measurements

Measuring cosmic rays is done the same way you did the source measurements. You will notice several differences in your spectra, but the data collection and analysis procedures are the same. In fact, you have already analyzed old cosmic ray data in the first part of this experiment. Some differences between source and cosmic ray measurements are listed below:

- *Different particles:* The source you are using for your experiments emits neutrons, while the cosmic rays detected by MoNA are mainly muons.

- *Different energy:* The neutrons emitted by the source have low energies, up to about 6 MeV (6.000.000 eV). The cosmic muons have very high energies, up to 4 GeV (4.000.000.000 eV).

- *Different deposited energy:* Neutrons and muons interact with the plastic scintillator in different ways. It is beyond the scope of this guide to explain these interactions in detail. What you need to know, however, is that a low energy neutron can deposit any fraction of its energy (even all of it) in the detector. So, the energy signal you get in the detector is in the range between “zero” and about 6 MeV. On the other hand, a high-energy muon will not deposit all of its energy, but only a small fraction of it, which depends on the thickness of the detector. Since all MoNA bars have a fixed thickness of 10 cm, the energy deposited by a muon in a bar will also be fixed and equal to ~20 MeV.

- *Different range:* Low energy neutrons will not travel very far in MoNA. Placing the source next to a bar will produce signals in that specific bar and also in 2 or 3 neighboring bars. On the other side, cosmic muons have such a high energy that they do not stop in MoNA. They have already traveled such a long way since they were first produced that a few meters of material does not affect them. They just loose a very small fraction of their energy in each bar. This means that a muon coming from the top will be detected by all 16 detectors of a MoNA layer.

- *Count rate:* Depending on its intensity and the distance from the detector, the neutron source can produce several signals in a MoNA bar in a short amount of time. This means that measuring for a short time (e.g. 10 minutes), you can have a spectrum with enough statistics to perform your analysis. In the case of cosmic rays, however, the count rate is not as high, and of course it cannot be changed. So in order to do your analysis you will need to collect data for more than 12 hours, to have enough statistics for your analysis.

Based on the above differences, you will be asked to study and explain some of the main characteristics of muons, such as their velocity and their angular distribution. In order to do that in a more efficient way, instead of asking you to calibrate the 144 MoNA detectors, the calibrations were done beforehand and you can use the calibrated position and time spectra.

Once you have the data you can perform your analysis and extract any information you need. At this point you and your group should think and propose an analysis procedure that can be used to measure some of the characteristics of cosmic rays. In this guide we include some ideas about measuring the velocity of muons and their angular distribution. If you have any different ideas for measuring the same quantities or something else, discuss it with the staff members. It is not guaranteed that all of your ideas can be easily applied in the analysis code. Things might get complicated if new parameters need to be created. At the end of this document there is a list of all the available parameters.

Muon angular distribution

5) Cosmic rays hit the earth from all directions. However, the ones that end up in our detectors do not come from all angles. We mostly see cosmic rays coming from the top and as the angle increases, the number of detected cosmic rays is reduced.

   a) Discuss within your group the reason for this reduction. Can you imagine how would the angular distribution of cosmic ray muons look like?

   b) It was found that the angular distribution of muons at the surface of the earth is $\propto \cos^2\theta$, where θ is the angle from the vertical direction. Draw on your graphical paper how a $\cos^2\theta$ distribution looks like (horizontal axis=θ, vertical axis=$\cos^2\theta$).

   c) How can you use the MoNA bars to choose muons that come in specific angles?

   d) There is a parameter created for you that corresponds to Xpos_top – Xpos_bottom (Xdiff_...15-...00). If we assume that you are using layer C, this parameter will have the name Xdiff_C15_C00 and it will give the difference between the position of interaction in the top bar (C15) and the bottom bar (C00). If you have muons going through layer C vertically, what would be the value of Xdiff_C15_C00?

   e) If the muons were coming at an angle of e.g +5 degrees, what would Xdiff_C15_C00 be equal to? Fig.4 will help you figure this out.

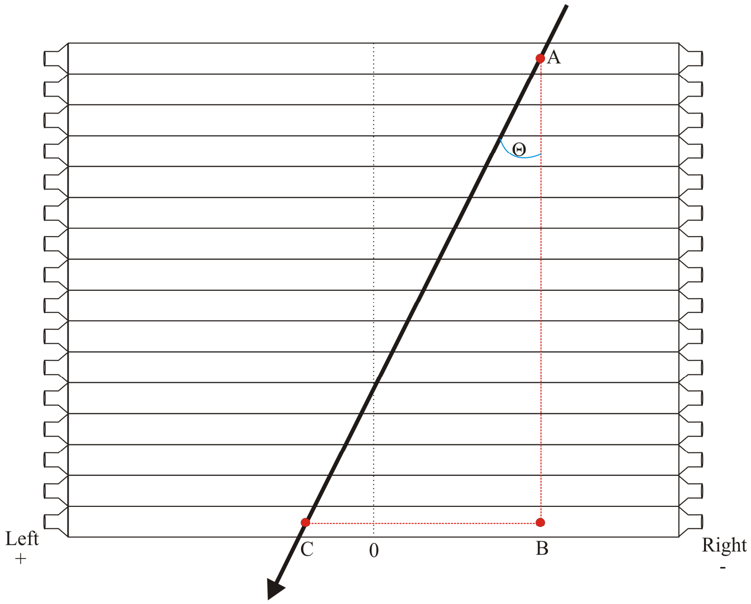


Figure 4 Geometry of incoming muon

f) Make similar calculations as in the previous step to fill the first four columns of table 2 for 10 angles between –90 and 90.

Table 2

Θ (deg)	**cos(Θ)**	**$\cos^2(\Theta)$**	**tan(Θ)**	**Xdiff_*15_*0**	**counts**	**Normalized counts**
-90						
-80						
-70						
…						
0						
…						
+80						
+90						

g) If you know that a MoNA bar is 200 cm long and 10 cm wide, calculate what is the maximum angle that a muon should have in order to be detected by the top and also by the bottom bar in the same layer.

h) Propose ways to increase this angle.

i) Now you can look at some spectra. Click on the button “X position difference” and then attach on your cosmic data run file and wait until all buffers are read in. When this is done, click on the “*Update all*” button.

j) You can use your mouse to check how many counts were registered for a specific value of Xdiff_*15_*00 (this is the y value showed at the bottom of the Xamine window). Use this method to fill in the fifth column of table 2.

k) In order to plot your results and compare to the expected $\cos^2\theta$ distribution you need to perform normalization. This means that you should make the peak of your spectrum and the peak of the $\cos^2\theta$ distribution the same. To do that, divide the numbers in column five with the number of count that correspond to angle 0 and write your results in column six. When you do that, the "Normalized counts" for angle=0 should be equal to 1 and the rest of the values should be smaller than that.

l) Use the plot you made earlier for the $\cos^2\theta$ distribution to draw the "Normalized counts" on the same axis.

m) How do the two plots compare?

n) Discuss within your group and explain the reason that your results are not as expected. How can you improve your results?

Muon velocity (optional)

6) First discuss within your group and propose a way to measure the velocity of a particle with MoNA. Write in your logbook a short description of the procedure you want to follow and discuss your ideas with the support staff.

   a) In spectcl there is an available parameter called Tdiff_*15_*00, where * is the name of a layer. For example, if you use layer E, the parameter will be called Tdiff_E15_E00 and it corresponds to the time difference Tmean_E15-Tmean_E00. For a muon coming from the top, do you expect this difference to be positive or negative? Discuss your answer with the support staff before continuing.

   b) Go to the "SpecTcl control" window click on the "Time of Flight" button and then use the "*Attach to file*" button to attach to the cosmic run you took overnight.

   c) All layers are equivalent so you can choose to study any layer you prefer.

   d) Wait until your spectrum has enough statistics (a well defined peak). Remember to check if you are satisfied with the limits and the binning of your spectrum.

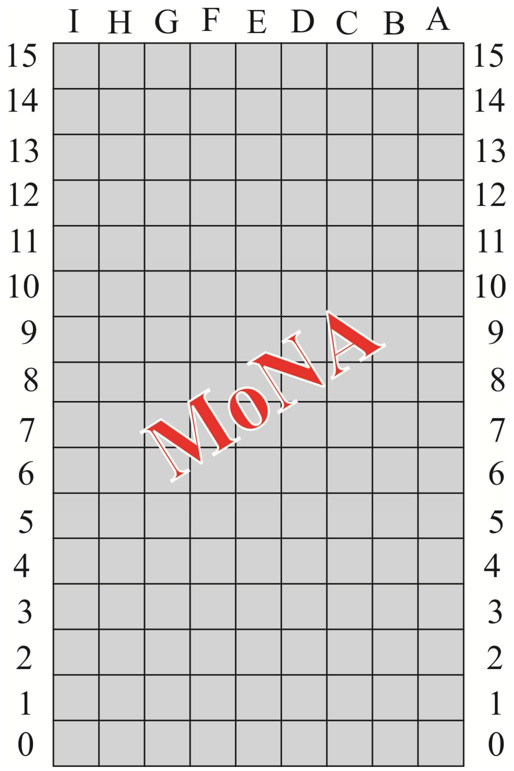
e) Does the peak in your spectrum appear at positive or negative times? Is this what you expected? Which is the main direction of muons?

f) Use your peak to estimate the time it takes for a muon to travel from the top bar to the bottom bar. Then use this time to estimate the velocity of the muons.

g) Ask the support staff to tell you what the velocity should be. Did you get what you expected?

h) Propose reasons and ways to improve your measurement.

Meaning of Parameters and Names



This figure presents a side view of the MoNA bars. The different layers are marked with letters A through I. In the same layer, the different bars are labeled with numbers 0 through 15. For example the top bar at the front layer of MoNA is A15.

Any time that there is a "…" it means that this information is different depending on which bar you choose and you should substitute "…" with the bar layer, bar number, or the letter "L" if it's the left photomultiplier and "R" if it's the right one.

…._tcal

This parameter records the time of the event on both ends of the bar. That's why there's a left and right for each bar.

Example: g08l_tcal and g08r_tcal are the left and right time parameters for the bar G8, respectively.

…._qcal

This parameter records the charge of the event on both ends of the bar. That's why there's a left and right for each bar.

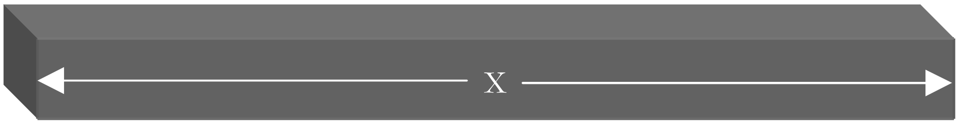
Here's an example: g08l_qcal and g08r_qcal are the left and right energy parameters for the bar G8, respectively.

…_qmean

This parameter takes the average energy of the left and right energy data collected for each bar.

..._xpos

This parameter will display where on the bar the event occurred. The center of the bar is 0cm and the left end is +100cm while the right end is -100cm.



…_tmean

This parameter takes the average time of the left and right time data collected for each bar. In other words, it is derived from TDC Left and TDC Right.

Qdiff_...LR

Calculates QDC Left – QDC Right.

Tdiff_...LR

Calculates TDC Left – TDC Right.

COG_...

Calculates $\frac{(P_l - P_r)}{(P_l + P_r)}$

Xdiff_...15-...0

Calculates Xpos Top – Xpos Bottom.

Tdiff_...15-...0

Calculates Tmean_Top – Tmean_Bottom.