

# International Muon Week Muon Speed Study

## April 1-5, 2019

### It's Here. Join us!

Student groups around the world will use their cosmic ray muon detectors to **measure speeds close to the maximum possible speed in the universe!** They will measure the average time it takes muons to traverse the distance between two detectors. By collecting data at more than one separation distance, the muon's speed can be calculated. A map will show participants' locations and be used to post their results. Students can also participate in video conferences hosted from Fermilab during the following week to discuss their results.

#### *Are you ready for International Muon Week (IMW) 2019?*

It's not too late to register using the link below to let our Cosmic Ray Fellows know that you are participating. <https://goo.gl/forms/SWv6xGIIR7YojdP2>

Here are instructions describing how to upload a link and comments to share your results. <https://forms.gle/Aip6zEW73WQmDXsE8>

In this message we share detailed instructions about the experimental technique. Contact us if you need assistance.

**Average Muon Speed technique:** measure the time ( $\Delta T$ ) it takes muons to travel from one detector to another, separated by distance ( $\Delta Z$ ).

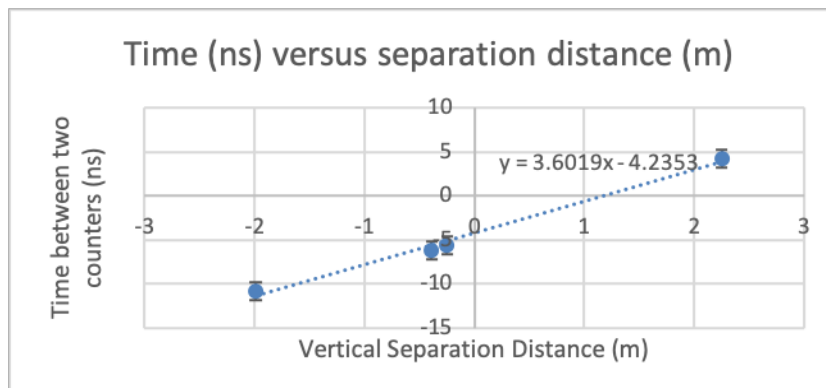
Naively, the average muon speed is therefore  $\langle V \rangle = \Delta Z / \Delta T$ . However, this makes an assumption that is not justified: that  $\Delta T = 0$  if  $\Delta Z = 0$ . We don't know if the signals from the two detectors reach the electronics at exactly the same time and generate exactly the same time measurement. We will calibrate away those unknown effects by taking data with the detectors separated by various distances. If we plot  $\Delta T$  as a function of  $\Delta Z$ , the inverse of the slope yields the speed.

We anticipate that participants will use two radically different kinds of detectors, but this technique applies to both. The standard QuarkNet scintillation counters can be moved to measure relative timing at different vertical separations. The distance between the tracking chambers in the EEE collaboration is fixed, however, given their tracking ability, the travel distance for each track is known precisely.

Here is an example from QuarkNet data taken at Fermilab using a stacked detector readout out by DAQ 6119. There are four counters in the stack however only the positions and the time between counters 1 and 3 are reported here. Compare the mean of the time difference between channels 1 and 3 (T3-T1) versus the counters' relative vertical separation. The speed is obtained from the inverse of the slope: speed =  $2.78 \times 10^8 \text{ m/s}$ .

Date	6119 ch1 Vertical Position (cm)	6119 ch3 Vertical Position (cm)	Displacement (cm)	T3- T1 (ns)	T3- T1 error (ns)	Number of events
10Nov18	231	6	225	4.26	2.88	8612
8Dec18	31	230	-199	-10.8	2.61	8257
2Mar19	45	6	-39	-6.15	2.79	16968
17Jan19	6	33	-25	-5.62	2.79	8241

Result of fit to 4 points is  $2.78 \times 10^8 \text{ m/s}$



Good luck. Please feel free to contact us if you would like assistance or more information.

### DATA COLLECTION PLAN

Verify that your detector is operational. Test that your hardware is running and collecting data. You can use data obtained before April 1<sup>st</sup>, or even after muon week if you like.

Try to collect speed data during the week of April 1-5. Collect data in at least two configurations of the detector.

We ask all users to place their detectors in a stacked configuration. Record the distance between a pair of detectors and measure the time difference between those detectors.

## QuarkNet Directions:

For QuarkNet users, cosmic ray muon detector (CRMD) help is available in the Cosmic Ray e-Lab at the Help Desk (upper right of e-Lab web page, looks like a life ring, <https://www.i2u2.org/elab/cosmic/teacher/forum/HelpDeskRequest.php>).

QuarkNet CRMD users should use the following DAQ commands to configure their detector DAQ for every run:

ST 3 5 report channel count status, 5-minute interval

WC 00 1F set two-fold coincidence (The two digits in the middle are zeros, by the way.)

CE computer enable

Don't forget to update your CRMD geometry so you can refer to it later.

Upload your data to e-Lab for each separation configuration. Run the Time of Flight (TOF) on single files. If you have 4 counters live, six histograms are generated representing the time difference between each pair of counters. The mean and error of the timing distribution is available under advanced controls. You will use the timing of only one pair throughout the experiment. (You could have your students use the other pair of counters to perform an independent speed experiment.)

[If you have other detectors you can use the TOF analysis controls to require them in analyzed events.](#)

Analysis help is available in e-Lab under Library/Resources

[Step-by-Step Instructions](#) and [Tutorial](#) - Learn how to understand the results of a **Time of Flight Study**.

Here are the direct links

Tutorial <https://www.i2u2.org/elab/cosmic/analysis-timeofflight/tutorial.jsp>

Step-by-Step <https://www.i2u2.org/elab/cosmic/library/resources.jsp#>

Advanced topics:

1. You get the best measurement by separating the counters by at least a meter. The time resolution of each counter is around 2ns. Since muons travel 0.6m in 2ns, a large counter separation is helpful. The statistical error on the mean of the timing distribution is smaller than the error of the distribution (by  $1/\text{SQRT}(\text{number of events})$ ), but that may be too advanced for a first effort.
2. Note that in the example  $\Delta T$  is not equal to 0 at  $\Delta Z=0$ . It might be an interesting exercise for students to discuss why. The answer is that we cheated and made the signal cable lengths unequal, to make a point about the need for calibration.

3. Why can we use the average speed? Isn't the speed different for each muon depending on its energy? This can lead to a discussion about relativity.
4. If you separate the counters by a large vertical distance, the rate of 2-muon triggers (where the muons come from directions not determined by angular acceptance defined by your two counters) can become large compared to the rate of one muon passing through both counters. The 2-muon background is difficult to remove, however, requiring other counters to fire can reduce this background. Time of Flight analysis controls allow you to set a software requirement on the trigger multiplicity or the require specific counters in the final histograms.
5. Not all muons travel perpendicular to the counters. Have students estimate effect of longer paths as muons traverse diagonally. What can they do to minimize the effect? How big is it?
6. Muons come from various angles with respect to the zenith. Students could collect data with detectors not stacked vertically if they are so inclined.

Regards,

Kevin, Jeff and Mark