QUARKNET ANNUAL REPORT 2017
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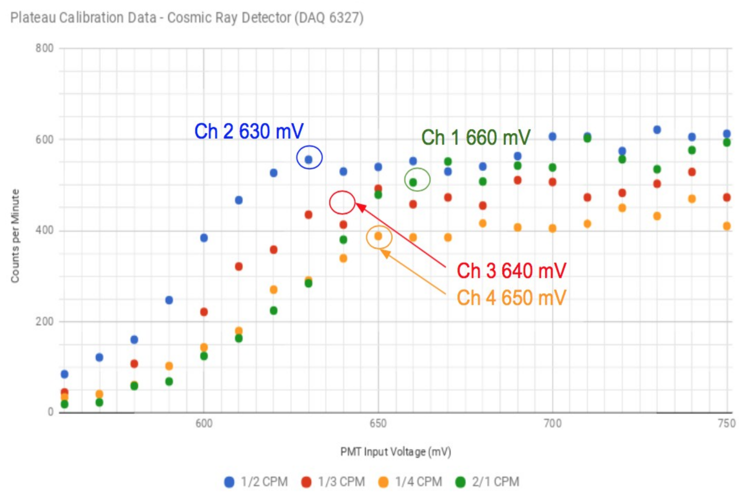
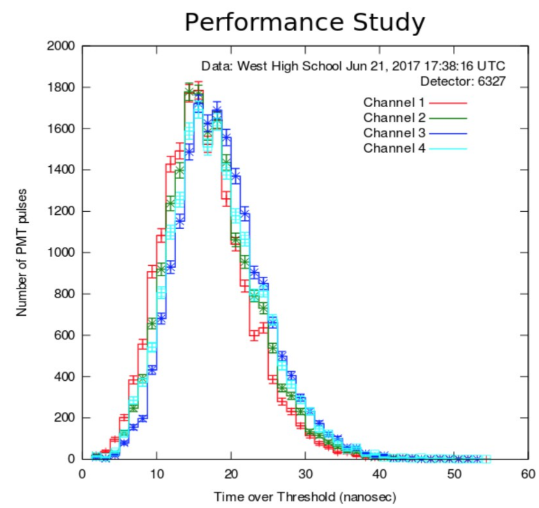
The summer 2017 is the first year for QuarkNet at UTK. Two teachers, Tommy Eggleston (West High Science teacher) and Erica Johnson (Halls High School Science teacher) were part of the QuarkNet program. There were two main goals the UTK center wanted to achieve:

1. Cosmic ray studies with the QuarkNet Cosmic Ray Muon Detector
2. Analysis of data from the MicroBooNE neutrino experiment leading to the planned International Neutrino Master Class Program

Both teachers performed exceptionally well during their internship period and will take leading roles moving forward.

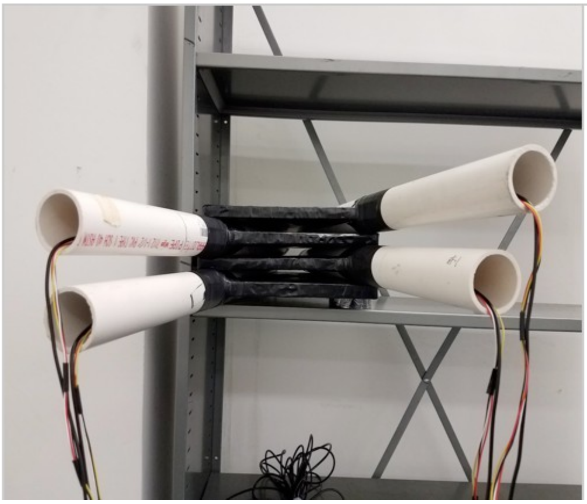
Cosmic ray muon studies with the CRMD:

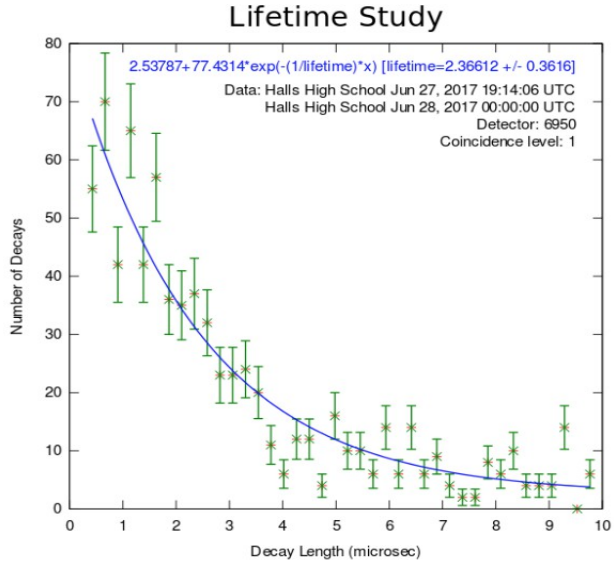




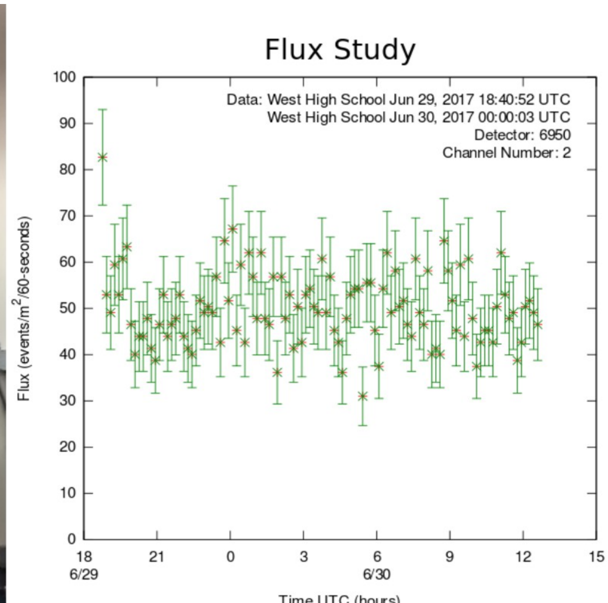
We received the QuarkNet CRMD kit in June and after the CRMD training workshop given by the QuarkNet fellow at UTK, the two teachers started operating the detector. Building the cosmic ray detector provided good hardware experience to the two teachers and taught them the basic elements that make a particle physics experiment. Among the first things, the first goal was to calibrate the detector by plateauing the Photomultiplier Tubes (PMTs). Although the teachers were given the settings for counts per minute at which the PMTs are expected to saturate, the teachers were instructed to perform the full calibration procedure to understand how calibration is typically done in experiments. Both teachers went through the calibration instructions available on the QuarkNet website and prepared their own documentation for calibration. The images above show the selected calibration points from the full calibration studies done by the teachers and the resulting performance plot for all 4 channels.

After the initial calibration, both teachers focused on measuring different properties of cosmic rays. Tommy Eggleston focused on measuring muon time of flight where as Erica Johnson focused on measuring the muon lifetime. The images below show the experimental setup by Johnson to measure muon lifetime. Johnson measured a lifetime of 2.35 microseconds with an error of 0.36 microseconds while the expected lifetime is 2.2 microseconds. Johnson then proceeded to explore the parameters that might effect the accuracy of this measurement. These parameters included chosen bin width, number of bins and the gate width. She changed these parameters and monitored how they affected the lifetime value and the background counts. For a particular set of parameters, the best value measured by Johnson was 2.20+/-0.14 micro seconds.

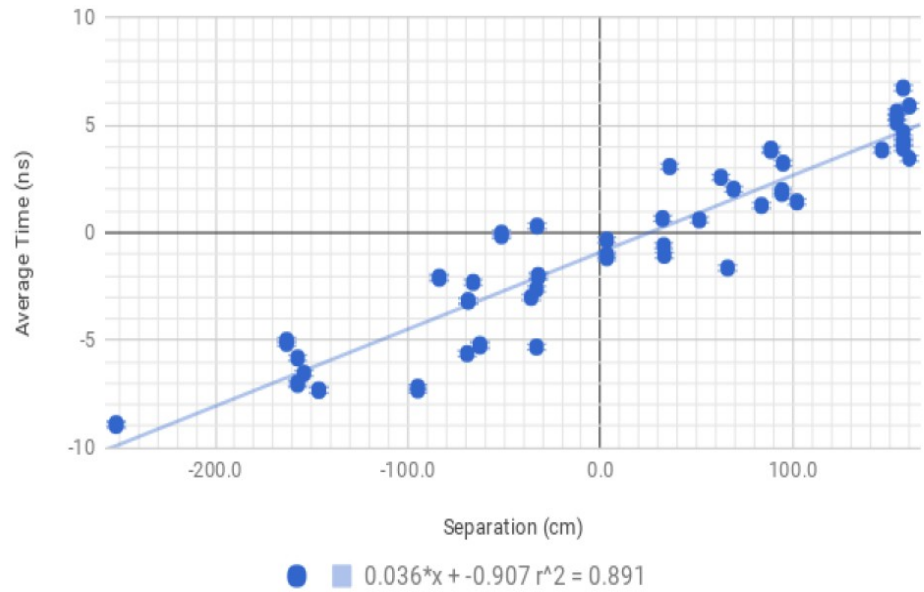




For the time of flight studies, Eggleston employed several stacked plate arrangements to create varying separations and calculated the time of flight value for each arrangement using the E-lab software. The images below show two such experimental arrangements employed by Eggleston and also the results of the cosmic muon flux study done by Eggleston to monitor the flux variation over a range of two days.



Based on the data collected for 15 different arrangements, Eggleston constructed a scatter plot of the time of flight and the plate separation. See the first plot on the next page. The slope of the straight line of best fit of the data points represented the reciprocal of the average speed of the cosmic ray muons. The average speed from the data was measured to be (2.78+/-0.146)E8 which falls within 7% of the accepted value for the muon speed. The R^2 value for the scatter plots was found to significantly stronger (0.891) which gives confidence in the fit used.

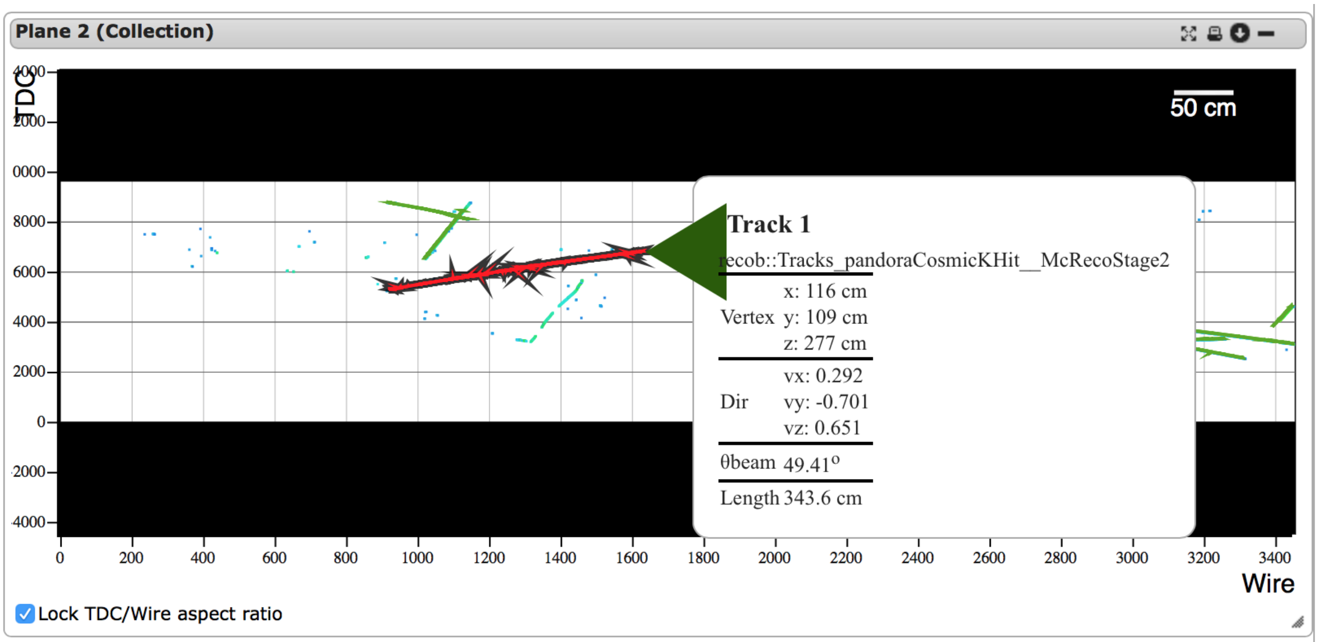


Data analysis with the MicroBooNE experiment:

The MicroBooNE experiment is built to explore the properties of neutrinos. Neutrinos are one of the fundamental particles and are second most abundant in the universe. Neutrinos hold clues to some of the most profound questions in the universe such as the observed matter dominant universe. Another actively pursued questions in neutrino physics is whether there are more than three flavors of neutrinos. The MicroBooNE experiment at Fermilab is aimed at answering this question. Since neutrinos cannot be directly detected as they are neutral, we study them through their interactions with other particles. MicroBooNE uses the innovative Liquid Argon Time Projection Chamber (LArTPC) technology to study neutrinos. This detector is placed in a large tank of liquid argon. Neutrino interactions with argon produce charged particles that ionize argon producing ionization electrons that drift towards the anode in the applied electric field. These electrons register as signals on the anode wire planes, which can later be used to reconstruct charged particle tracks.

The images above show the MicroBooNE cryostat being lowered into the experimental hall (left) and one of the first neutrino interaction events observed in MicroBooNE (right). As a first step, a few lecture/discussion sessions were held to teach the teachers about basics of neutrinos, MicroBooNE experiment and how the liquid argon time projection technology works, along with what techniques experimentalists use to detect neutrino interactions. To help teachers get familiar with neutrino interaction topologies in liquid argon, two practice exercises were conducted where teachers were given 20 event displays in each session and are asked to identify the various particles (tracks) shown in the event displays and form a summary table listing what type of particles were identified. This exercise helped the teachers greatly to both understand how we reconstruct neutrino events and how to identify various particles and their topologies.

After this initial step, the next step was to identify and implement a event display that is suitable for high school teachers/students to perform data analysis visually without having to use any coding. The ARGO event display (http://argo-microboone.fnal.gov) developed by Prof. Nathaniel Tagg (MicroBooNE collaborator) was identified as the most suitable browser based event display that can be used by teachers. In collaboration with Prof. Tagg, both teachers explored various features of the ARGO event display and gave extensive feedback to further tune it so it is more suitable for high school students. This process is still ongoing. But, both teachers performed a small physics task with the version of the display that was available at the time. The goal was to measure the velocity of drifting signal ionization electrons and also to calculate the purity of the liquid argon. To make both of these measurements, tracks that cross the detector from anode to cathode, or crossing tracks are required. Based on the information available in the display for the distance covered by tracks in the drift direction (see the image below), and the total drift time to reach the anode plane, based on two clean muon tracks, the teachers were able to calculate a drift velocity of 116 cm/micro-second. The expected value for the drift velocity is 114 cm/microsecond.



For the purity of argon measurement, again crossing tracks are selected. To measure purity, the simplest method to compare the charge at the beginning and end of the tracks was adopted. The difference in the deposited charge between the two points gives an estimate of the charge loss due to presence of impurities in argon. Tagg provided a tool (see the image below) that lets the users to select a region of space on the track and obtain information on averaged charge and time in that region. Knowing the directionality of tracks is important for this measurement since we need to identify the beginning and end of track. Implementing the directionality in the display is currently being worked on. With the tools available at the time, both Johnson and Eggleston went on to measure the liquid argon purity using cosmic muon data from MicroBooNE and observed a electron lifetime value of 8 ms. The electron lifetime value gives a handle on understanding how much charge attenuation happened in the detector and is generally inversely proportional to the impurity contamination in the liquid argon. The 8 ms lifetime measurement by the teachers indicates a signal loss less than 30%. More follow up work will be done on both these data analysis studies. Ultimately the goal is to take the experience gained from Johnson and Eggleston and implement it in the International Neutrino Maser Class that is currently being planned for various Fermilab liquid argon experiments.