Determining Effects of a Neutrino Beam on Muon Flux

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Abstract

QuarkNet students used muon detectors to determine the muon flux in response to overhead burden. After analysis revealed that there may be a correlation between a neutrino beamline from where the experiment was being housed and the muon flux, the data was normalized in response to the beamline. Results and detailed analysis are shown below.

Motivation

Students set out to determine whether overhead burden affects the rates of cosmic ray muon flux. This was done by placing a muon detector underground in the MINOS experiment and moving the detector further away from a vertical access shaft, where there was less overhead burden. However, a neutrino beam was present during part of the cosmic ray measurement period; as such, muons from the beam contaminated the cosmic ray results. An additional detector was added to search for the presence of beam muons and to develop a correction factor for the cosmic ray data.

Materials and Procedures

- Three QuarkNet Cosmic Ray Muon Detectors, assembled and attached to computers to constantly run analysis
  - One surface module to serve as a control measuring moun flux on the surface
  - Two Tunnel Modules to measure the muon flux within the tunnel: TC for cosmic ray muons and TB for muons created by the neutrino beamline.
    - TB and TC Inputs: 1, 2, 3, 4
    - Muon Trigger Beam: TB 142
    - Muon Trigger Shaft (aimed both towards and away): TB 13 and TB 23
    - Muon Trigger Large Acceptance: TC 34
    - Muon Trigger Medium Acceptance: TC 234
    - Muon Trigger Small Acceptance: TC 134 or 1234
- The detectors were assembled and layed out according to the geometry shown in Figure 1, including the surface detector, which had the same geometry as detector TC1. Detectors TB13 and TB23 were aimed 26° to the vertical. Over 6 weeks, measurements were taken at 1-week intervals at different positions in the MINOS tunnel. We obtained a readout of the intensity of the proton beam that created the neutrino beam every 5 minutes. This schedule allowed us to determine what percentage of a particular day when data was being gathered had the beamline on. The data was then analyzed and visualized.

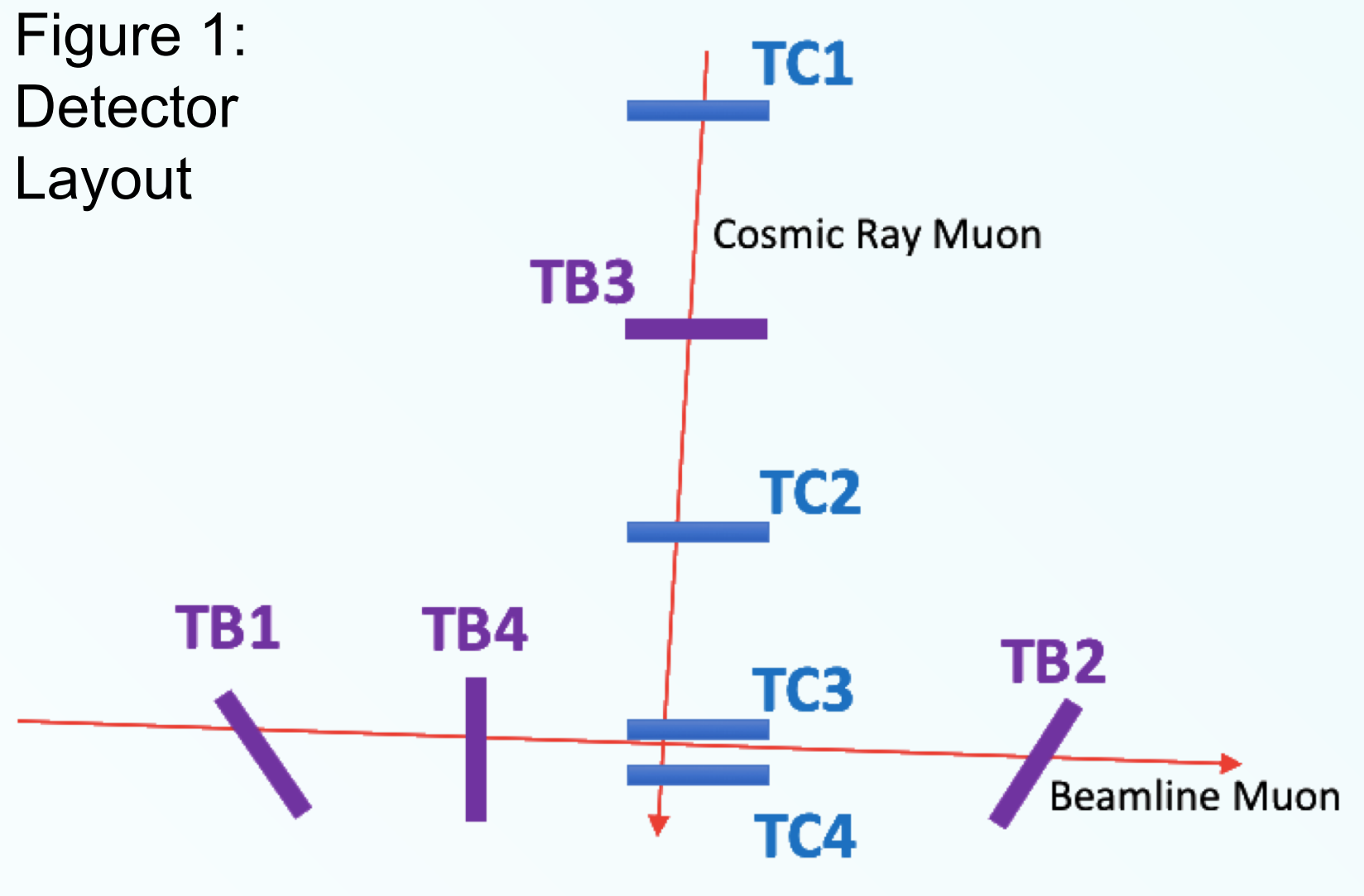


Figure 1: Detector Layout

Analysis

Figure 2 shows that the TC counts are affected by the neutrino beam. The TC large acceptance 234 counters measured 9% more counts with the beam on versus beam off. A detector, identical to TC, operating on the surface, was used to correct for the variation of the cosmic ray flux as a function of time. Figures 3 and 4 show that the number of background muons due to the beamline is proportional to the amount of time that the beamline is on during the data run. All three graphs involved normalizing the muon rate to one when the beam was on during 100% of the day. We developed a correction factor for the TC large acceptance data using the slope of the normalized plot in Figure 2. For each day of the week-long run, the following was calculated:

A = Total number of muon counts during one day
B = % of time the neutrino beam was on during the day

Corrected counts = $A*(1-(B*0.091))$

We then summed all the corrected counts for each day of the run and divided that sum by the total number of hours of the run to get the counts per hour for the week of data. This process was done for each position along the tunnel. The beam on and off times were determined by using records from Fermilab that specified when the beam was operational by 5-minute intervals. Although it appears there is some correlation between position in the tunnel and the normalization factors, we used an overall correction to simplify normalization.

Conclusion

The primary goal of the experiment was to measure the muons made by cosmic ray collisions in the atmosphere. It was discovered that when the neutrino beam is active, it also creates muons because of the neutrinos interacting with rock. Because of this systematic effect on muon counts, a correction factor is needed. There is not enough data with the beamline totally off to determine a correction factor for each position in the tunnel. An average factor developed from data at all positions was used to correct the large acceptance TC data.

Results

Figure 2

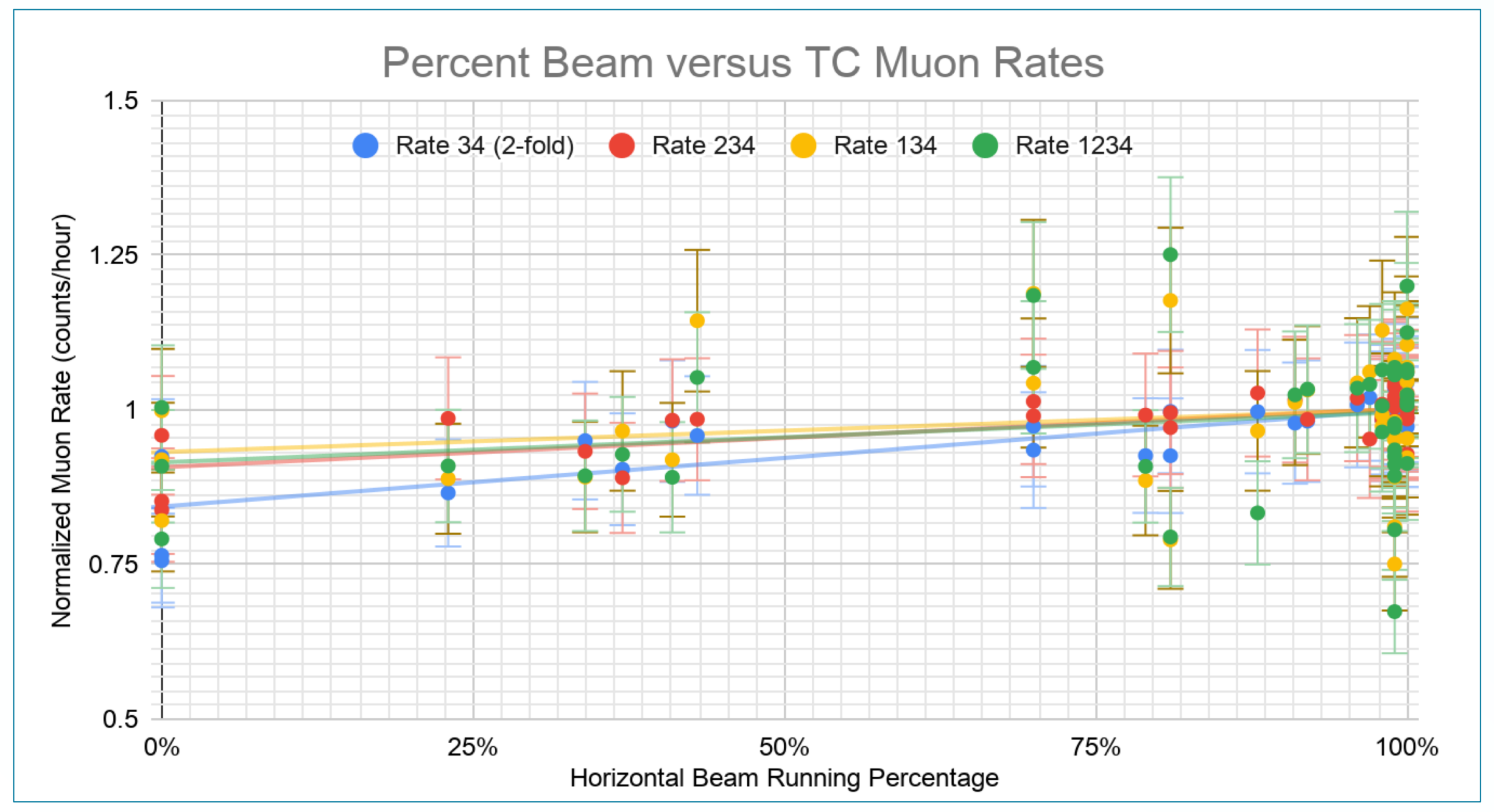


Figure 2 shows the TC count rate versus percent beam on for different distances from the shaft. As the beam running percentage increases, so does the normalized muon rate. The trend lines assist in illustrating this. This suggests a strong correlation between the muon rates and the neutrino beamline, indicating that a correction of the TC data is required.

Figure 3

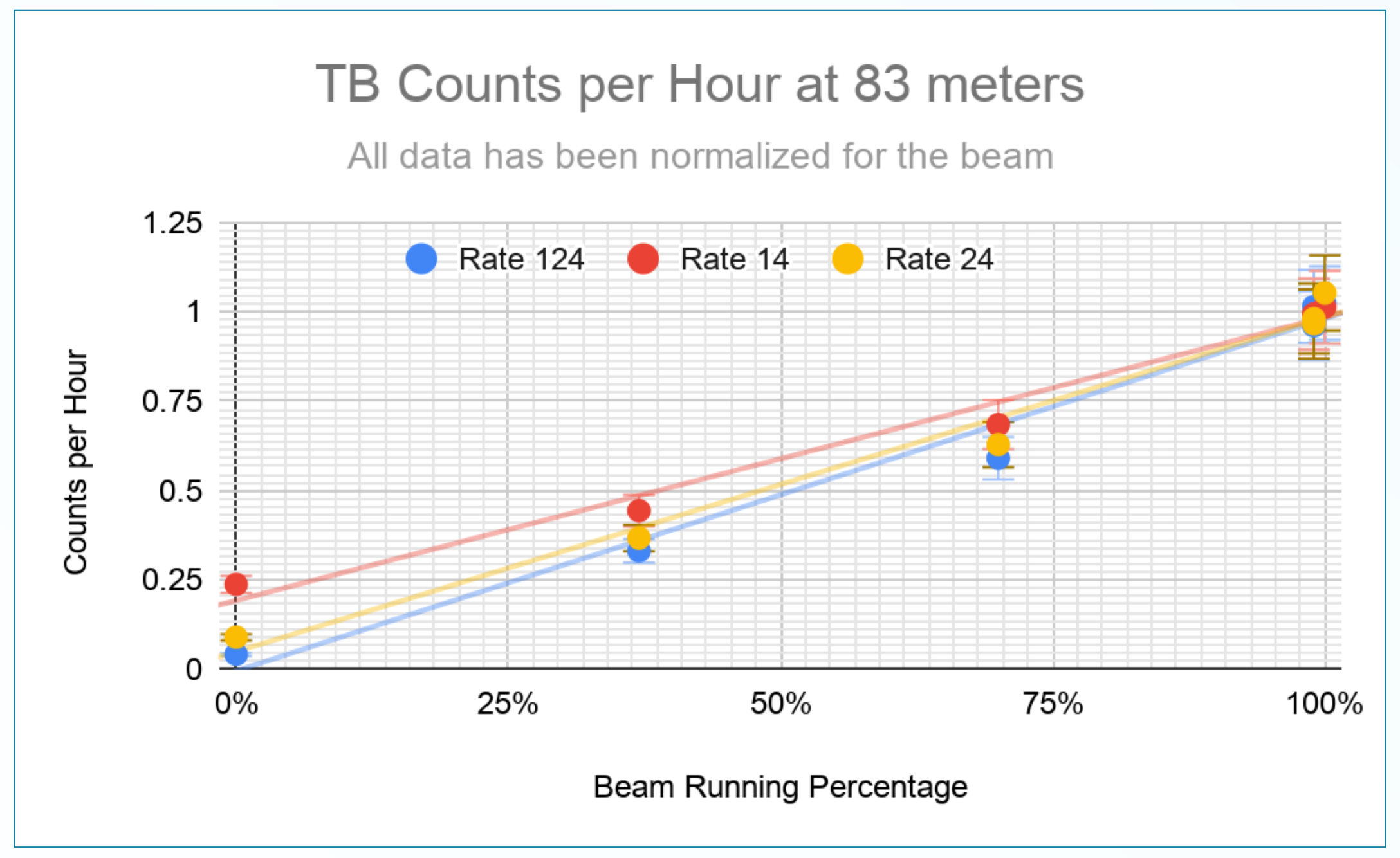
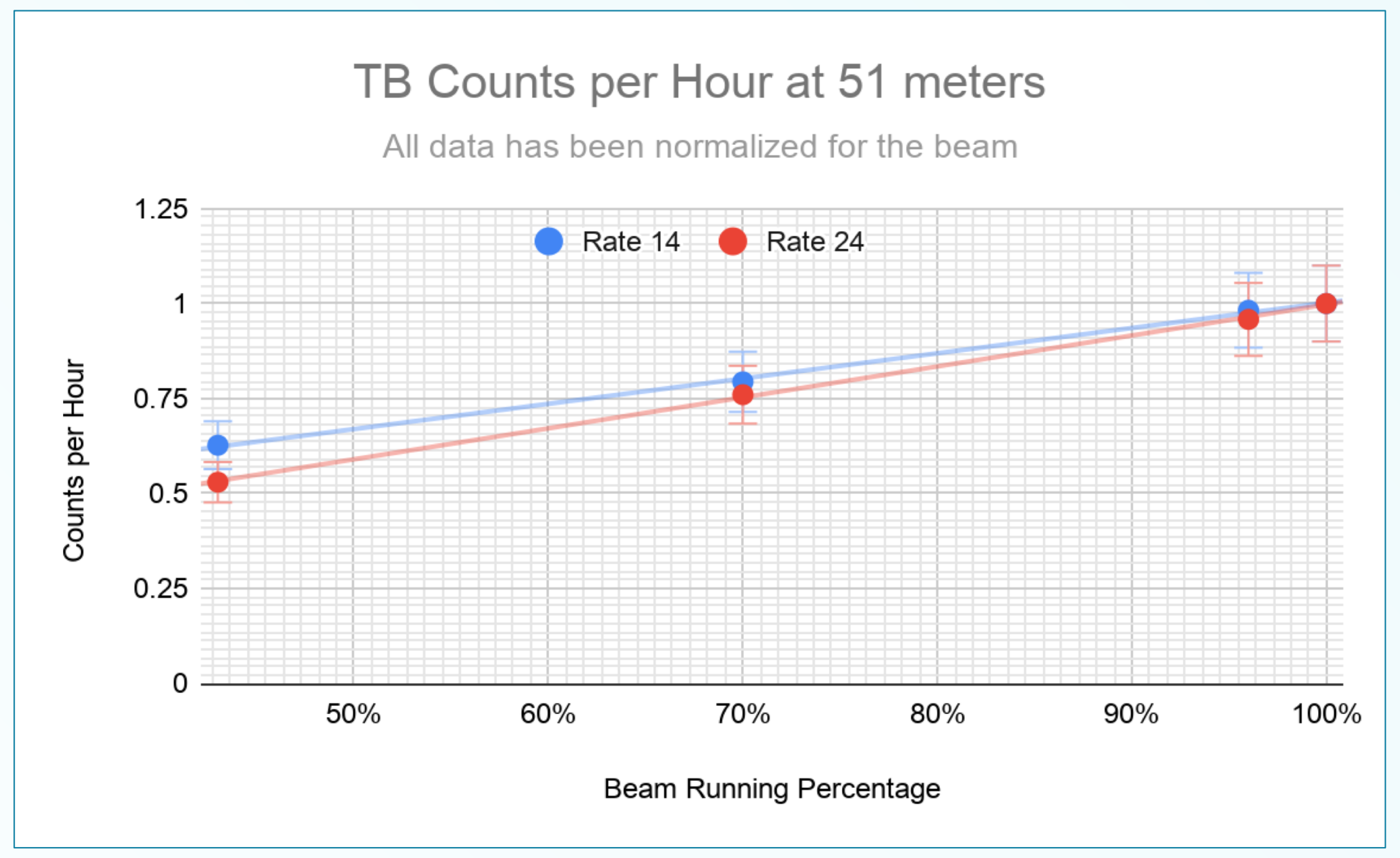


Figure 4



Figures 3 and 4 show the TB counts at different distances from the shaft. Each data point represents one day of the week-long data run. The graphs show that when the neutrino beam is on there are more muon counts being introduced into our data. The data is normalized as described in the “Analysis” section. These two graphs further prove what Figure 2 illustrates, which is that the beamline influences TC muon counts.

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