

# Rejuvenation of the Durham Neutron Monitor



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## Introduction

### History

By 1957, IGY neutron monitors had gained popularity as a dependable means of detecting and counting cosmic rays. They use lead (Pb) to create ~1 MeV neutrons from much more energetic cosmic-ray neutrons. A moderator further reduces their energies down to thermal levels to be counted in a proportional gas counter. However, the IGY monitors only captured about 2% of the neutrons produced in the lead. In 1964, a new neutron monitor design was internationally adopted, called the NM64. Although similar to the IGY, there are several changes that result in a neutron detection rate 3.3x that of the IGY. Our neutron monitor on campus is in Durham, New Hampshire, at an elevation of 20 m and a geomagnetic cutoff of 2.21 GeV. It started operations in 1964. In 2006, it was moved to a site a mile away off the main campus. It consists of three banks each with six BP-28 tubes in an NM64 configuration. The tubes are 190.8 cm long and roughly 15 cm in diameter.

### Motivation

Neutron monitors contribute to the field of space weather. With monitors at different altitudes, asymptotic directions and cutoff rigidities, when we observe the same GLE with two or more monitors, we can learn more about the power spectra density and the pitch angle distribution of the particles.

Monitoring cosmic rays is important in the context of space weather, because GLE events, in particular, can pose a hazard to astronauts and passengers and crew of high-altitude aircraft. Cosmic rays are also a concern because they can disrupt or damage spacecraft equipment and other space assets.

### Physics of Cosmic Rays

The solar wind with its embedded magnetic field shields the heliosphere from some of the galactic cosmic-ray (GCR) population. The extent of this shielding at Earth depends on the phase of the solar cycle. We are further shielded by way of our magnetosphere and our atmosphere. When cosmic rays coming to Earth are sufficiently energetic, they can be detected on the ground. Additionally, the Sun is a transient source of energetic charged particles, called SEPs. Events where SEPs are detected (in addition to GCRs) by neutron monitors are called Ground Level Enhancements (GLE). GLEs constitute just one focus of our research.

### Physics of Neutron Monitors

Cosmic protons interact with the atmosphere, producing secondary neutrons. These neutrons induce fission in the lead producer, producing several 1-10 MeV neutrons. The polyethylene sleeve around the tube serves to moderate the fast neutrons down to thermal levels. If they diffuse into the proportional tube, the neutrons can be captured on  $^{10}\text{B}$ , yielding a  $^7\text{Li}$  nucleus and an  $\alpha$  particle. The two products recoil in opposite directions and ionize gas molecules. The freed electrons are multiplied by the accelerating electric field. The total collected charge is proportional to the deposited energy of the  $^{10}\text{B}$  fragments. The current pulse is amplified before digitization.

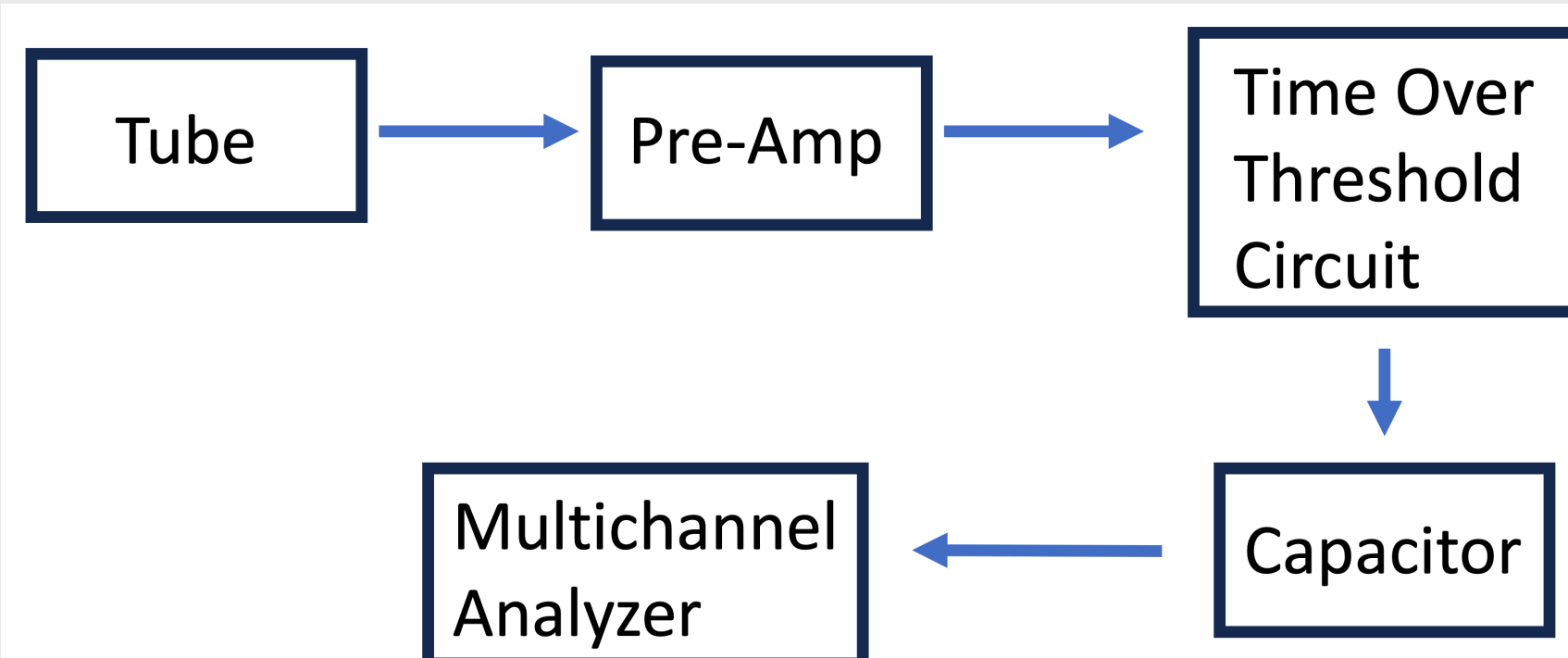


Figure 1: Block Diagram of the Circuit

When the thermal neutron interacts with  $\text{BF}_3$  gas, there are two possibilities, depending on which excited state the B finds itself in. The Q-Values of 2.792 MeV or 2.310 MeV correspond to the ground and first excited states, respectively. 94% of the time, the reaction ends in the excited state. Because some reactions take place in proximity to the detector wall, either the lithium or alpha particle can leave the detector, not depositing its full energy in the gas. This is called the Wall Effect and produces a continuum of energy deposits. A good neutron monitor spectrum, obtained from tube B4, is shown in Fig. 2. The ground state of  $^7\text{Li}$  sits at ~0.43 V, while the first excited state is at ~0.36 V. The wall effect appears at 120 mV. Fig. 3 shows the spectrum of a problem, but usual tube.

## Methods

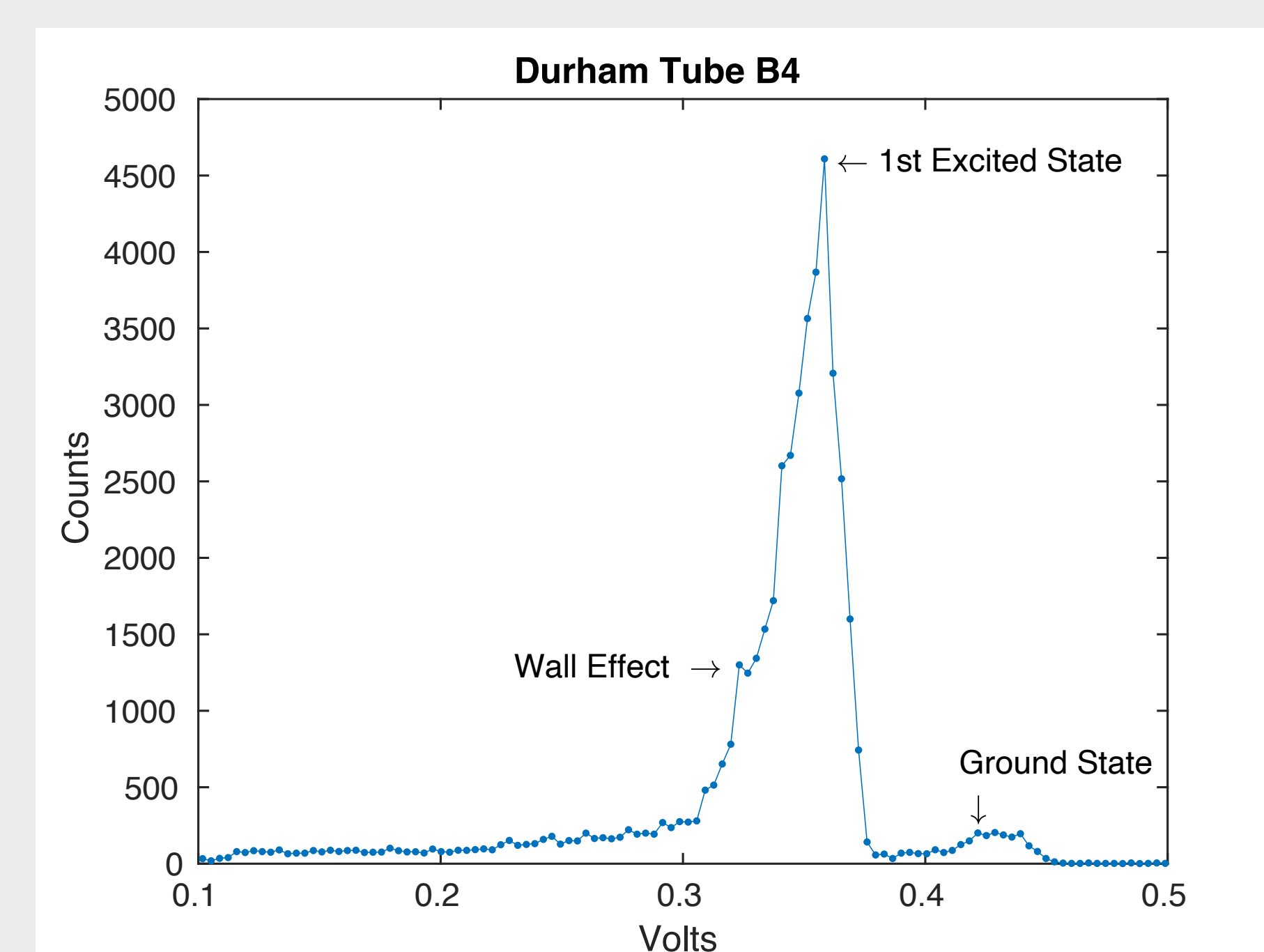


Figure 2: An Example of a Good Spectrum

### Computer Support Equipment

We collect data using a GUI programming environment called LabVIEW™. It is versatile and known for its hardware connectivity, making it well suited for this project. Additionally, because we require precise timing, we use another National Instruments product, the CompactRIO™ or cRIO. The cRIO is essentially an FPGA-based LINUX OS computer with no moving parts that runs LabVIEW™. The dedicated functionality of the cRIO and LabVIEW™ work to provide rugged and reliable performance, especially for a project that requires internet connectivity in remote locations.

### Data Corrections

Once the raw data have been collected from the monitor, we need to remove instrumental effects and barometric pressure variations. Barometric pressure is a measure of the depth of the overlying atmosphere. The greater the pressure, the more air there above the monitor site and the greater the attenuation of the secondary cosmic-ray neutron intensity. The pressure-corrected count rate is given by the following equation:  $n(p) = n_0 e^{(p-p_0)/\lambda}$ . Here,  $p_0$  is the average pressure at Durham,  $n_0$  is the true count rate and  $\lambda$  is the barometric coefficient. We also must correct for any tubes not functioning properly. To do this, we remove the faulty-tube counts from the total and then multiply the remaining count rate by the ratio of total tubes to working tubes, taking into account whether the tube is on the end of the instrument or the interior.

### Anomalous Behavior

#### Count Rate Spikes

Approximately every hour, two ten second bins become merged into a single twenty second bin, creating a spike in the count rate. After reviewing the historical data, we have concluded that the problem started when a new cRIO was installed in 2017. Despite the fact that the code did not change, something about the newer cRIO is causing this conflict with the code. We have circumvented this issue so far by creating one-minute bins from the ten second ones. The presence of a twenty second bin does not matter when all the counts within the minute are being summed anyway. We suspect the problem is caused by the interface of the cRIO with the time server.

#### Tube Spectra Spikes

Some individual tubes have problems as well. Once a month, the LabVIEW code constructs a histogram of the pulse heights in each tube for diagnostic purposes. These spectra exhibit spikes in the data. See Fig. 3. These spikes are absent when using external electronics. We find that these spikes are not a result of the software, bins merging or non-uniform bin widths. We will be running tests on all possibilities that we can think of and will replace whatever part that is causing the spikes.

### Database

All count rates and tube spectral data are saved to individual text files. These must be manually downloaded through PuTTY. Data analysis over a span of time longer than a single day requires that we concatenate multiple files. To date, we use MATLAB to do this with success. The appended data sets only exist within MATLAB itself and the individual files must be uploaded manually. We are currently building a database that will house all of the data. We are developing this database in PostgreSQL. Additionally, we are able to apply pressure and efficiency corrections to the data, as well as upload it to the database, using Python code. The database currently stores the uncorrected total count rate, the corrected total count rate, the pressure and the time at the start of the measurement. The raw data has many more measurements in different forms, such as the temperature, humidity and count rate for each tube and can be included in the database for very low level studies.

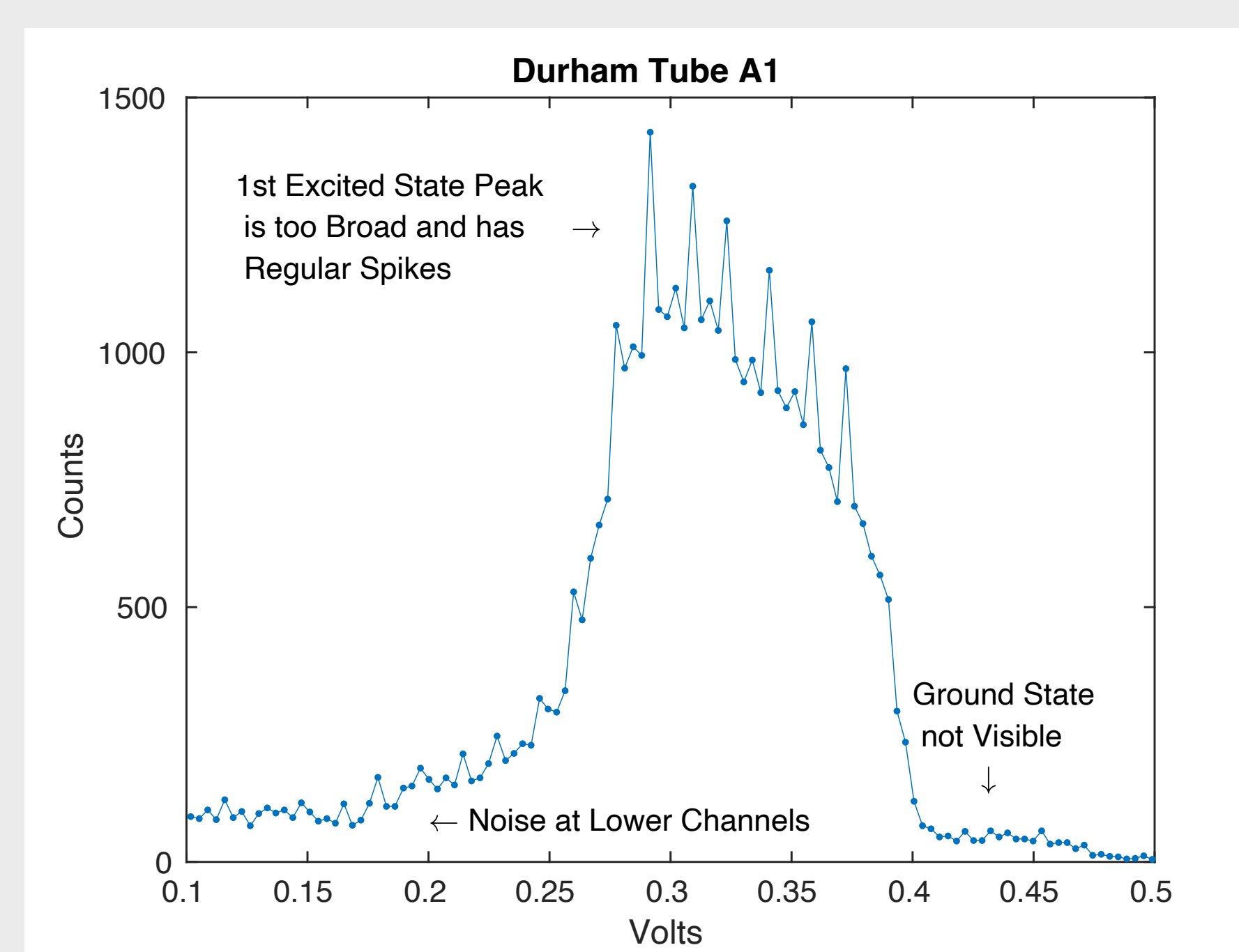


Figure 3: An Example of a Bad Spectrum

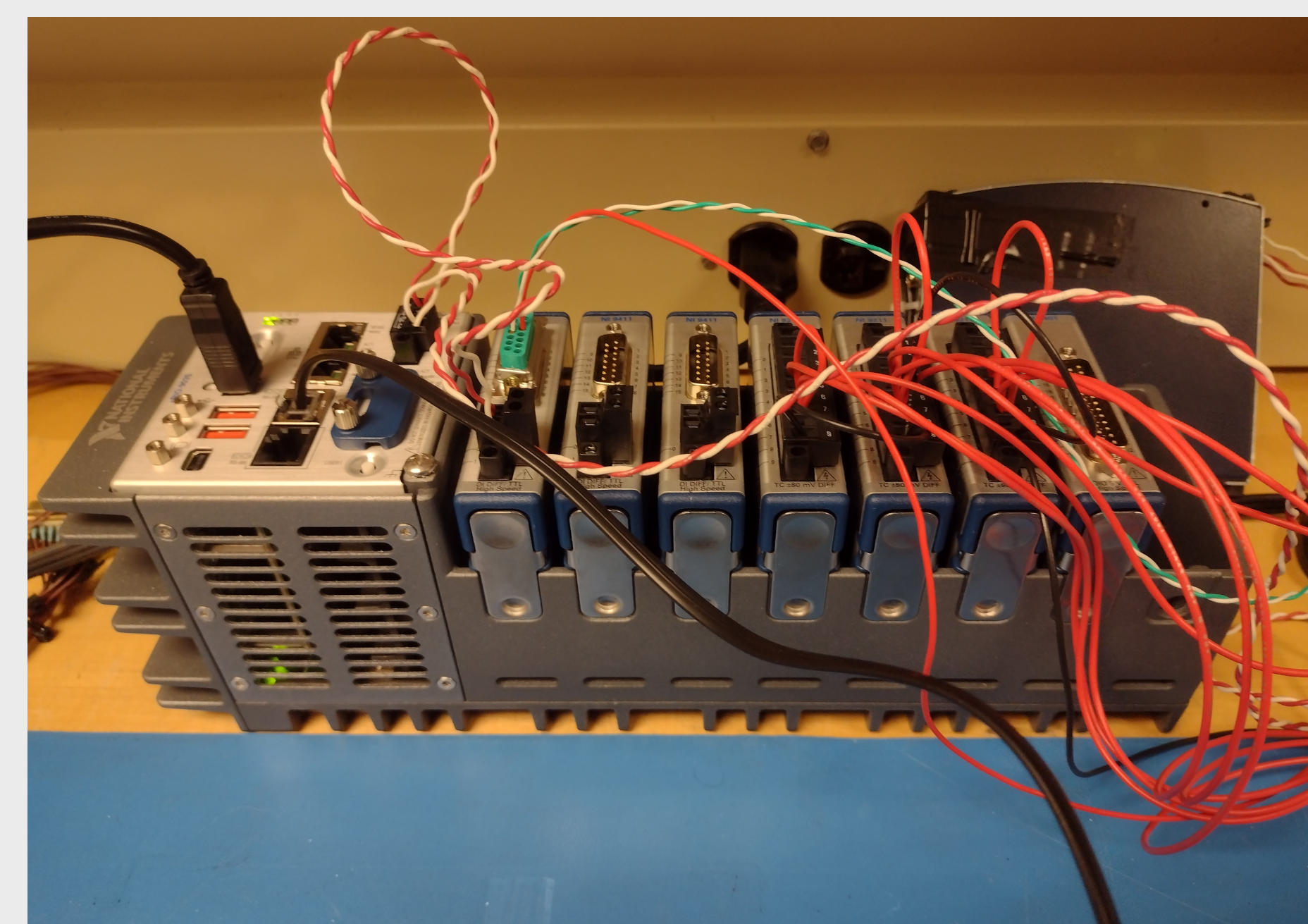


Figure 4: The CompactRIO

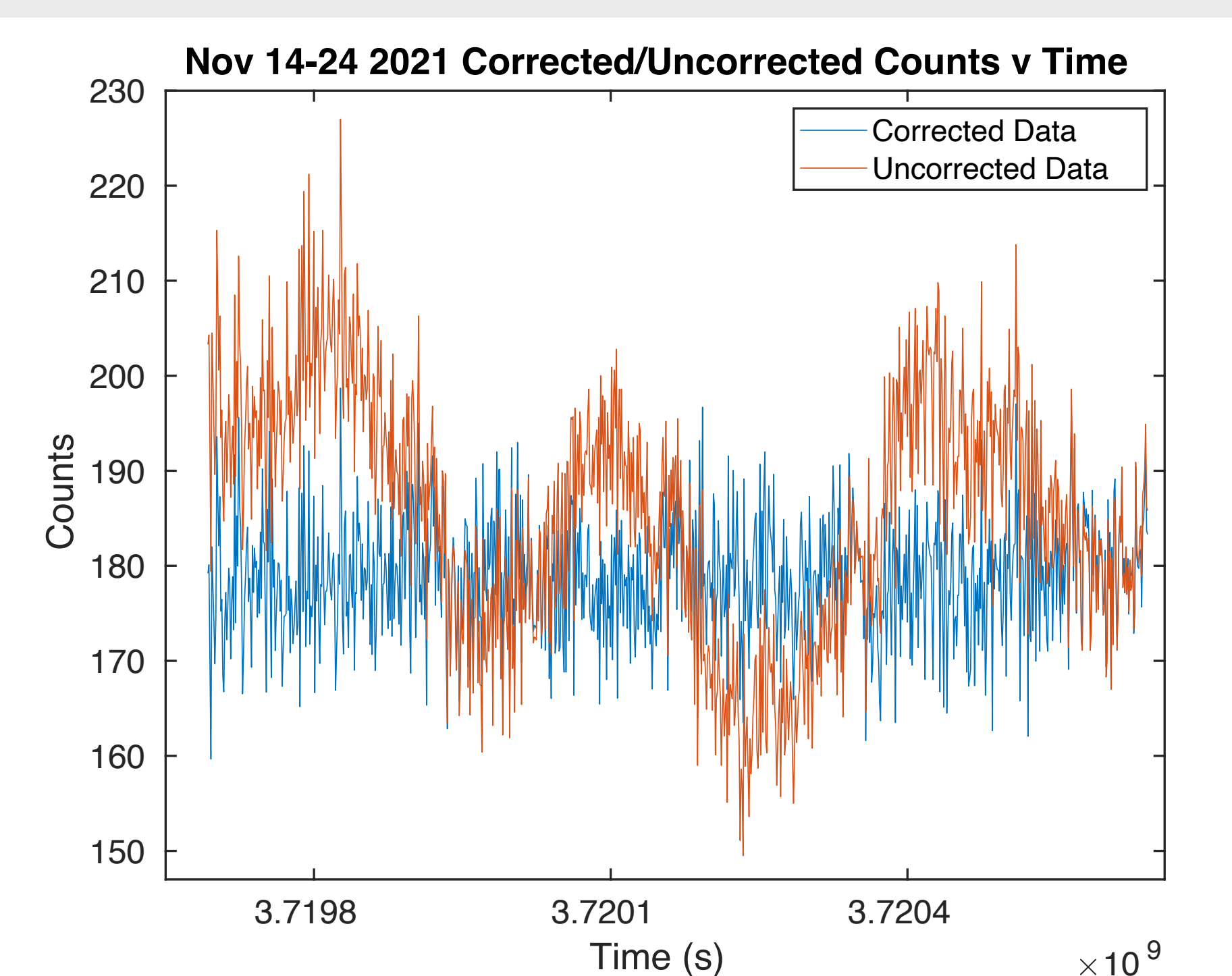


Figure 5: Comparison of Pressure Uncorrected/Corrected Data



Figure 6: The 18 tubes of the Durham Neutron Monitor

## Results

### Current Status

Overall, the UNH Neutron Monitor is getting a long overdue makeover. Other equipment, such as spare tubes and pre-amp boards, have been tested and documented. Aside from a few issues, such as some with poorer resolution, our tubes in Durham are healthy and consistently providing us with data. The LabVIEW™ code, which was previously undocumented, is being thoroughly reviewed and documented. Barometric pressure correction was built into the LabVIEW™ code, but has been moved to the post-processing computer. Updates to the barometric coefficient are now easily installed. The local database is up and running but manual and infrequent uploading is still required.

### Resolution v Count Rate

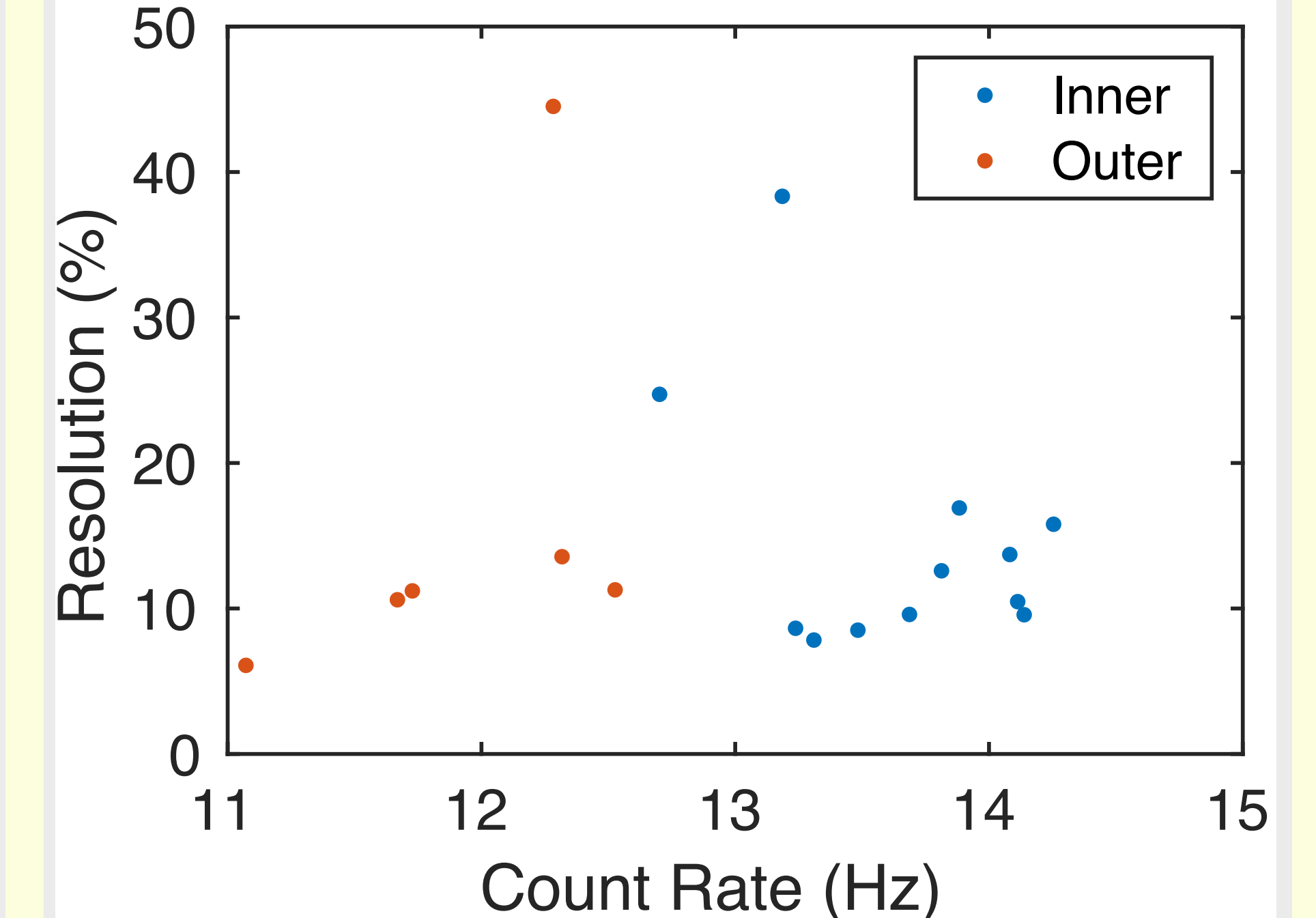


Figure 7: Each Tube's Resolution Relative to its Count Rate. Even Tubes with Poor Resolution have Acceptable Count Rates

### Future Plans

Our current pressure sensors are sufficiently sensitive but uncalibrated, requiring drift corrections. A new precision ( $\pm 0.1$  mb) barometer will be integrated with the monitors and pressure data will be part of the main data stream. We will next repeat this makeover for the monitor on the summit of Mount Washington, after which we repeat for the monitor in Leadville, CO. We have been collecting data from them but in-person testing and tube replacement is overdue. Additionally, we will soon be adding our data to NMDB, the NM database supported by the EU. In doing so, we can contribute to the realtime monitoring of GLEs and other events. We are currently building the software to automate data gathering, pressure correction and other instrumental corrections for uploading to NMDB.

## Conclusions

Overall, the neutron monitor work has been receiving a long overdue makeover, starting with the monitor at Durham. The health of equipment has been tested and documented in a systematic and thorough way not done before. A database is being built from the ground up and will be operational soon. The pressure correction was re-evaluated and is now part of the post processing system. Based on this experience, we can repeat this process for our other monitors.

## References

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4. Upgrading the Mount Washington Neutron Monitor by Katelyn Giles (2010)
5. [https://www.ni.com/en-us/shop/compactrio.html?gad=1&gclid=EAlaIaQobChMI-9X4tN-5gAMVw1FyCh2VBw2IEAAYASAAEGlkYPD\\_BwE#?cid=PSEA-7013q000001rC7sAAE-CONS-GOGSE\\_150020924350&utm\\_keyword=ni%20compactrio](https://www.ni.com/en-us/shop/compactrio.html?gad=1&gclid=EAlaIaQobChMI-9X4tN-5gAMVw1FyCh2VBw2IEAAYASAAEGlkYPD_BwE#?cid=PSEA-7013q000001rC7sAAE-CONS-GOGSE_150020924350&utm_keyword=ni%20compactrio)