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Quark Net High School Cosmic Ray Projects

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Abstract:

QuarkNet High School teachers and students perform experiments with cosmic ray muons. Their data is available to all on the i2u2.org site; enable measurements of muon flux, speed, and lifetime. The pandemic restricted access to many detectors, so QuarkNet provided virtual resources allowing users to carry out simpler experiments with already uploaded data. Some QuarkNet high school groups have also carried out more complex projects, e.g. Solar Eclipse 2017, MUSE at Fermilab, storm tracking, and g-2, that required assembling entire physics collaborations.

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1. Introduction

QuarkNet is a professional development program for high school teachers through which fifty high energy groups in the USA have been providing authentic research opportunities for teachers and their students for over two decades. Schools have participated in activities with access to data from experiments at the Large Hadron Collider and the neutrino program at Fermilab. Many schools have also been provided with cosmic ray detectors. Those schools have developed their own experiments using muons.

The QuarkNet cosmic ray effort is modeled on high energy physics collaborations: groups of scientists coming together to tackle complex scientific challenges. Long-term relationships are built between physicists and high school teachers. They design experiments utilizing muons and can carry out those investigations in three levels of complexity: analyzing existing data samples; collecting their own data; and creating collaborations among schools to build experiments that may span multiple years.

2. Data collection and basic experiments

The standard QuarkNet cosmic ray detector consists of four scintillation counters, photo-multiplier tubes with Cockcroft-Walton bases, a data acquisition card[1], and GPS unit to establish absolute time. Data collected is uploaded to a central server (e-Lab) and shared with all schools. e-Lab also contains tutorials on basic experiments and analysis tools with which schools develop their own experiments. The analysis tools enable schools to study detector performance, muon flux, the muon lifetime, muon speed, and structure of cosmic ray air showers. Schools carry out calibration of detectors, experimental design, data collection, and analysis for their individual projects. Plots and presentation posters of results are all created in e-Lab. A typical result for a muon lifetime experiment using a vertical stack of scintillation counters is shown in Figure 1.

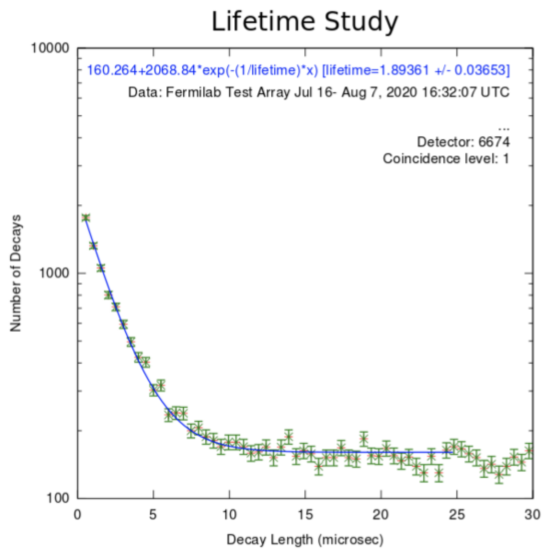

Figure 1. The number of muon decay candidates per 0.5 microsecond bin is presented versus time. The region between 300 nanoseconds and 25 microseconds is fit to yield a lifetime of 1.89 +- 0.04 microseconds with a random background of 160 events per bin.

3. Virtual analyses

4. As a response to the pandemic when access to detectors was restricted, QuarkNet developed a set of simple experiments that anyone could perform using existing data in e-Lab. There are 500K data files (in detector-day units) in e-Lab, however, subsets of data were curated to serve as well-defined data samples for several experiments: flux; muon speed easy; muon speed complete; muon lifetime; and exploring large array showers. These analyses were heavily used by QuarkNet teachers. Although the number of data files uploaded during the pandemic dropped by a factor of two due to detector access, the number of analyses performed increased. These simpler analyses also allowed teachers to involve their entire class in cosmic ray activities, rather than only the students who had self-selected to work with the detectors directly.

5. Measurements requiring collaboration

A major goal of QuarkNet has been to establish collaborations between faculty and teachers. During summers, workshops organized by university groups bring teachers and students together to train new participants and to explore new experimental ideas. Teachers constantly encourage their students to design original studies involving muons and sometimes they create projects that require larger collaborative efforts[2]. With the design of more sophisticated experiments multiple schools have banded together, sometimes building collaborations involving multiple university centers. QuarkNet staff support via mentoring, detector prototyping, and developing new analysis tools. Several experiments are presented in this section to demonstrate the power of teachers working together.

4.1 Time dilation

The teachers from a center in Chicago went on a field trip to carry out a measurement of the muon flux on the roof of the Sears Tower, as well as at the earth's surface. They constructed a portable detector, measured the muon rates at both locations, and on the roof, added absorber to account for the 400m of missing air. In addition to demonstrating that time dilation was required to explain their results they also measured the muon lifetime at both locations to eliminate the possibility that the muon lifetime might vary with altitude. Teachers were excited to share their direct experience with special relativity with their classes.

4.2 Total eclipse

Teachers realized that even though Hess had demonstrated that the sun was not the major source of ionized particles in the atmosphere, no one had published a measurement of the muon rate during a total solar eclipse. They intended to improve upon their upper limits obtained from day/night comparisons. Teachers developed a grand plan to measure the muon flux in the direction of the sun, at different angular scales, across the USA during the next eclipse. In 2017, a core group developed telescope designs using existing QuarkNet detectors, shared plans with schools around the country, and defined how to perform consistent measurements at all sites. Data was collected by over fifty detectors across the USA. After conclusion of data taking, a previous measurement from 1936 was found[3]; the schools improved those upper limits of cosmic rays coming from the sun[4]. During preparation of a paper to appear in *The Physics Teacher*, a discrepancy among astrophysics collaborations' modeling of the location of the shadow of the moon, obtained for high energy cosmic rays, was uncovered. The teachers are currently building an apparatus to measure the location of

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the moon shadow with low energy muons. Again, the plans will be provided to other QuarkNet schools; they hope that after observing the shadow directly, upper limits on cosmic ray production from the sun can be improved during the next total solar eclipse in the USA in 2024.

4.3 MUSE (Muon Underground Shielding Experiment)

Teachers submitted a successful proposal to Fermilab to measure the rate of cosmic ray muons 100m underground in the NUMI neutrino beamline. They built three detectors: one to stay on the surface to monitor the muon flux over time, an identical detector to measure the vertical muon rate underground, and a third detector underground to measure cosmic ray muons at 30 degrees from the vertical, as well as to monitor any possible background along the beamline. Over a three-year period, they developed the proposal, explored prototype detectors, collected data, and presented results at conferences[5]. Schools measured muon rates as a function of depth and crudely imaged the access shaft. They were excited when to discover that the neutrino beam's interactions in the surrounding rock created a muon background to their cosmic ray measurements that had to be subtracted.

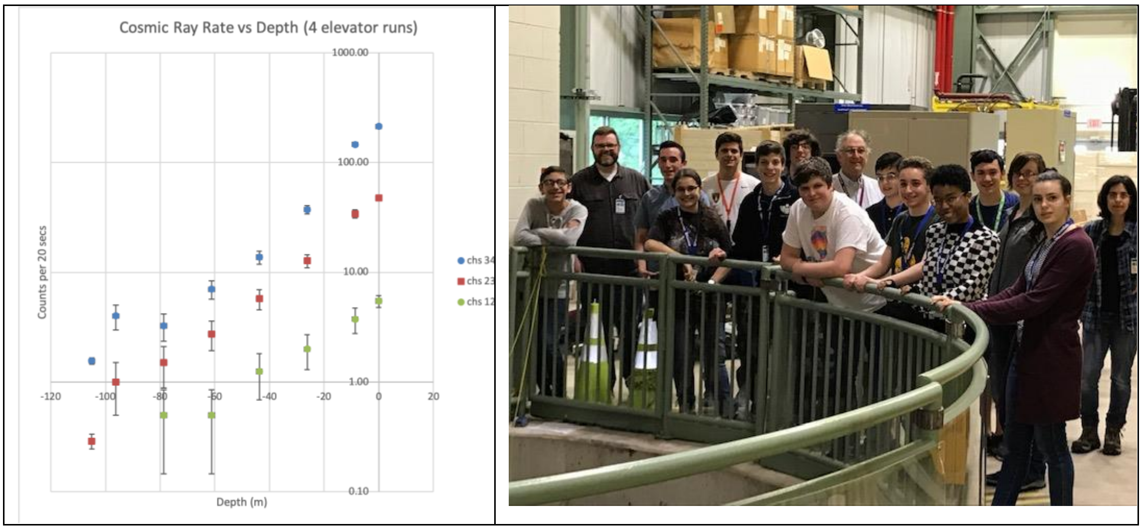

Figure 2. Left, the rate of vertical cosmic ray muons as a function of depth for three angular acceptances. Right, MUSE collaboration members at the NUMI access shaft.

4.4 Additional cosmic ray projects

Three more projects help demonstrate the benefits of combining schools to tackle interesting research problems: measuring muon multiplicity in air showers in a public space; tracking storms across Kansas; and developing a travelling g-2 experiment.

A group of schools from four states brought their detectors to Washington, D.C. to detect air showers in the four corners of the lobby of the National Air and Space Museum. Students and teachers measured the muon multiplicity distribution and explained their project to the public in real time, exploring science and public outreach simultaneously. Some students also met with their congressional representatives.

Schools across Kansas are organizing to use the muon flux dependence on atmospheric pressure to track storms across the state. They will joined by other groups, including Hawaii and Puerto Rico.

A muon g-2 measurement using cosmic rays is currently being developed. Schools have measured an up-down asymmetry in positive muon decays from a metal absorber used to reduce negative muon decays via muon capture. They have established that using four scintillators and the existing readout system, they should be able make a 10% measurement in a month-long run. A magnet is under design with the help of physicists at Fermilab. To share this opportunity to measure this fundamental constant with a broader community, the teachers plan to move the apparatus among schools. New e-Lab tools have been created (Figure 3) to make this measurement possible.

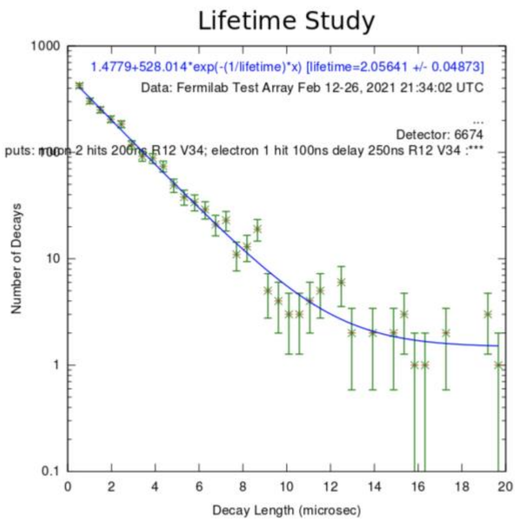

Figure 3. The muon lifetime of electrons emitted upward from muon decays in a metal absorber. The lifetime is found to be 2.06 +- 0.05 microseconds.

6. Summary

QuarkNet provides professional development for high school teachers, developing long-term relationship between faculty mentors and teachers. Investigations of cosmic ray muons provides a component where schools perform authentic research spanning design, calibration, data collection, analysis, and presentation of results. Three levels of sophistication are available: analysis of existing data; collection and analysis of a school's own data; and collaborations of schools for more difficult measurements. Since teachers can participate over many years, they challenge themselves to carry out increasingly complex measurements. Teachers and students have presented results at conferences and some results have been accepted for publication.

7. Acknowledgements

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7.References

[1] S. Hansen, et. al., Low-Cost Data Acquisition Card for School-Network Cosmic Ray Detectors. [arxiv.org/pdf/physics/0311060].

[2] Teachers Nate Unterman (near Chicago) and Jeff Rodriguez (near Cincinnati) suggested studies of cosmic rays during an eclipse and muon g-2, respectively.

[3] Y. Nishina, et. al., Measurements of Cosmic Rays during the Solar Eclipse of June 19 1936, Japanese Journal of Astronomy and Geophysics, Vol. 14, p.265

[4] M. Adams, et. al., QuarkNet Coordination of a Cosmic Ray Experiment Outreach Project During a Total Solar Eclipse, PoS, Vol ICRC2019, p1045 (2019). DOI: https://doi.org/10.22323/1.358.1045

[5] N. Unterman, et. al., High School Students' Muon Underground Shielding Experiment (MUSE), PoS, Vol ICRC2019, p170 (2020). DOI: https://doi.org/10.22323/1.358.0170

Presentations at AAPT Jan. 2020, San Diego:
M. Sensor, T. Valsamis, A. Sears, N. Unterman, Facilitating the High School Muon Underground Shielding Experiment (MUSE)
J. Miller, B. Grey, N. Unterman, Muse Cosmic Ray Muon Rates Elevator
E. Winkler, E. Copeland, P. Graham, N. Unterman, M. Senser, Profiling Muon Flux in Fermilab's MINOS Tunnels

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