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Adapting the Cosmic Watch for the Classroom

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QuarkNet is a particle physics outreach and education program in the United States. We have learned from our own experience and from international colleagues, especially in Japan, of the usefulness of the Cosmic Watch small cosmic ray detector. We are in the process of testing multiple units and adapting them for use in laboratory investigations in high school physics classes. This presentation will report progress and prospects.

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Introduction

QuarkNet [1] is a U.S. teacher development program to bring the content and practices of particle physics to high school classrooms through activities in which teachers and students can analyze authentic particle physics data. Cosmic Ray Studies are an important part of the program because they enable participants to measure muons. The QuarkNet cosmic ray detector [2] is ideal for investigations by small groups: it is robust and precise but also fairly sizable and expensive, so that one QuarkNet teacher might only have one of these available. The authors of this paper worked to create an inexpensive, portable solution so that class sets of detectors could be provided for whole-class laboratory investigations. They found such a solution in the Cosmic Watch [3], pioneered by Spencer Axani of the Massachusetts Institute of Technology. QuarkNet had a relatively large number of these small detectors built for experimental use by teachers during the 2022-23 academic year and, then, for more intensive testing by the team in summer 2023.

1.1 The Cosmic Watch Cosmic Ray Detector

The Cosmic Watch was developed by Spencer Axani of the Massachusetts Institute of Technology as a "simple, physics-motivated machine and electronics-shop project for university students and schools." [4]. In 2019, Daniel Kallenberg built several of these small detectors for QuarkNet. Subsequently, in 2020, just before travel became restricted, Kallenberg and Cecire, with collaborator Joel Klammer, all members of QuarkNet, were able to visit colleagues in Asia who were using the Cosmic Watch. In particular, they participated in an "Accel Kitchen" [5] workshop at Hiroo Gakuen in Tokyo, where physicist Kazuo Tanaka of Tohoku University (now at University of Tokyo) directed local high school students and teachers in experiments with the Cosmic Watch. QuarkNet staff decided to build a larger number of these detectors.

1.1.1 Use case

QuarkNet has a well-developed cosmic ray studies program and has produced a several hundred robust classroom cosmic ray detectors. However, budgetary considerations and space constraints in classrooms prevent these from being instruments that can be distributed to a physics class for small groups. The Cosmic Watch is smaller, less expensive, and electronically simpler. This constrains their use in some ways but also makes production of "class sets" of 10-20 detectors possible. Where the QuarkNet cosmic ray detector is ideal for small, highly motived teams of students to do in-depth investigations, the Cosmic Watch is ideal for distribution to students in a high school laboratory setting to do experiments to introduce them to cosmic ray physics.

1.2 Testing the Cosmic Watch

The University of Notre Dame QuarkNet Center is unique among the 52 centers in the QuarkNet program in that it is able to support seven weeks of research for a group of about 24 high school teachers and students each summer. Kallenberg, Chorny, and Wegner, with help from Senior Technician Daniel Ruggiero, produced 48 Cosmic Watch detectors in the summer of 2022. These were, in part, distributed to QuarkNet teachers locally and nationally so they could "try them out" in the U.S. 2022-2023 academic year. The detectors were mostly returned by summer 2023 for more systematic testing by the authors. Descriptions of several tests and their applicability to classroom use follow.

1.2.1 Counting rates in two-fold coincidence

We determined early in the process that the optimal use of the Cosmic Watch in the classroom is with two-fold coincidence, that is, with one detector triggering off the other. The rates for individual untriggered Cosmic Watch detectors are quite high due to internal noise: two-fold coincidence counts eliminate most of the noise. One counter is stacked on top of the other for this purpose and they are connected by a simple stereo audio cable to transfer current and send triggering signals. A typical singles rate is about 2-3 Hz while the rate in two-fold is about 0.1-0.2 Hz when one detector is stacked directly on top of the other. Rates and total counts can be read from the display on the face of the detector or on a computer via USB with appropriate software.

Almost all expected use cases for a high school physics class involve reading the rates directly from the face, so an immediate concern is at what point the rate can be read reliably. The first few counts are not reliable due to very small statistics. Collecting data on a Raspberry Pi with Node-Red software, Kallenberg measured rates as a function of two-fold count. He found that the rates varied quite a lot over the first 5 counts, but flattened to a reliable number after 20 coincidence counts. The results from three trials with the same set of two detectors converged at about 50 counts (Figure 1). Thus, it is reasonable to ask students in a classroom to wait for 20 counts to get a reasonably accurate rate for their set or 50 counts for even greater reliability. Even 10 counts is “not too bad” and it is up to the instructor to decide how to best trade accuracy for time in her or his class.

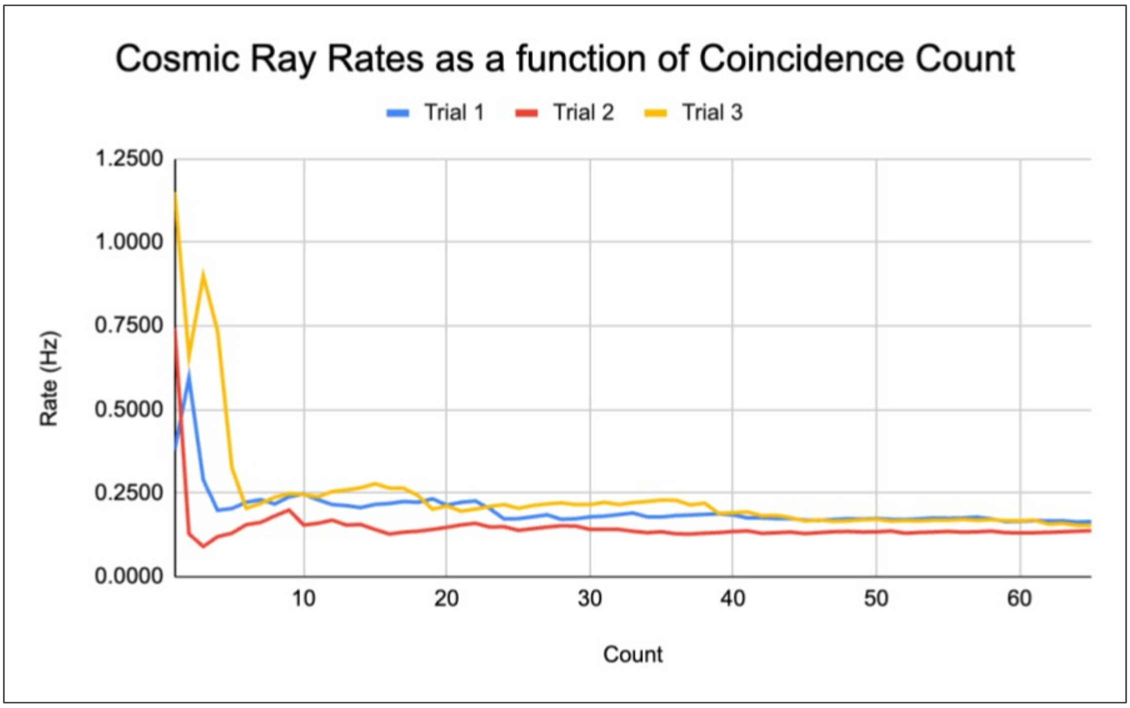

Figure 1. Results of test to determine stable coincidence rates.

While complete consistency between detectors is not expected, it is helpful to see if their two-fold rates are close. Kallenberg tested this as well with three detector pairs (A, B, and C) and found, using rates from coincidence counts 20 to 30, that the three counters were mostly within 25% of their average. This means that the operations of the pairs are similar but, in comparing or combining results across a class, the instructor should introduce students to a normalization procedure.

1.2.2 Zenith angle measurement

One of the first classroom experiments we discussed for the Cosmic Watch is measuring the rates with the axis of two detectors in coincidence making various angles with the zenith. High school students Karban and McNeely made this measurement with three different sets. To be sure the acceptance was sufficiently directional, the students placed the detectors in each of three pairs at a distance of 2.5 cm apart from the top of one to the bottom of the other. For each pair they calculated a normalized rate at zenith angle θ as $R(N) = [C(\theta)-(C(H)]/[C(Z)-C(H)]$, where $R(N)$ is the rate normalized to the difference between zenith (θ=0°) and horizontal (θ=90°) rates, $C(Z)$ is the raw rate at the zenith, $C(H)$ is the raw count at the horizontal, and $C(\theta)$ is the count at some angle between 0 and 90 degrees from the Zenith. Their results (Figure 2) showed, as expected, that the normalized rate decreases with increasing angle consistent with a proportionality to $\cos2\theta$ [6]. A test using the simpler normalization $R(N)=C(\theta)/C(Z)$ yields a similar result.

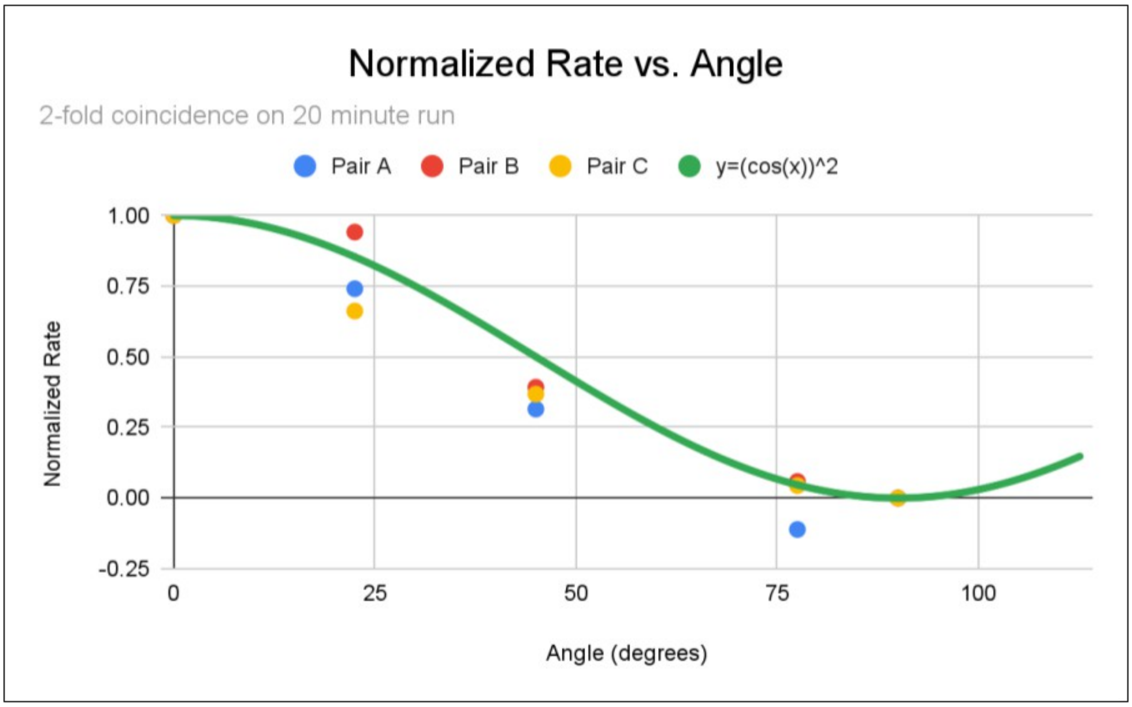

Figure 2. Normalized coincidence rate as a function of Zenith Angle.

Whichever, if any, normalization the instructor chooses, this simple experiment is expected to be a standard for classroom use due to its intuitive result and the discussion of what causes the rate to decrease with zenith angle.

1.2.3 Separation of counters

It is also possible for groups of students to study the effect of separation of counters on the coincidence rate. Cecire did a simple measurement on his desktop with a pair of counters. He separated the counters vertically, one unit vertically above the other, at several different heights. The minimum height was set at 5 cm as this is the vertical height of one Cosmic Watch detector: when one is stacked directly on the other, the internal scintillators are that same distance from each other.

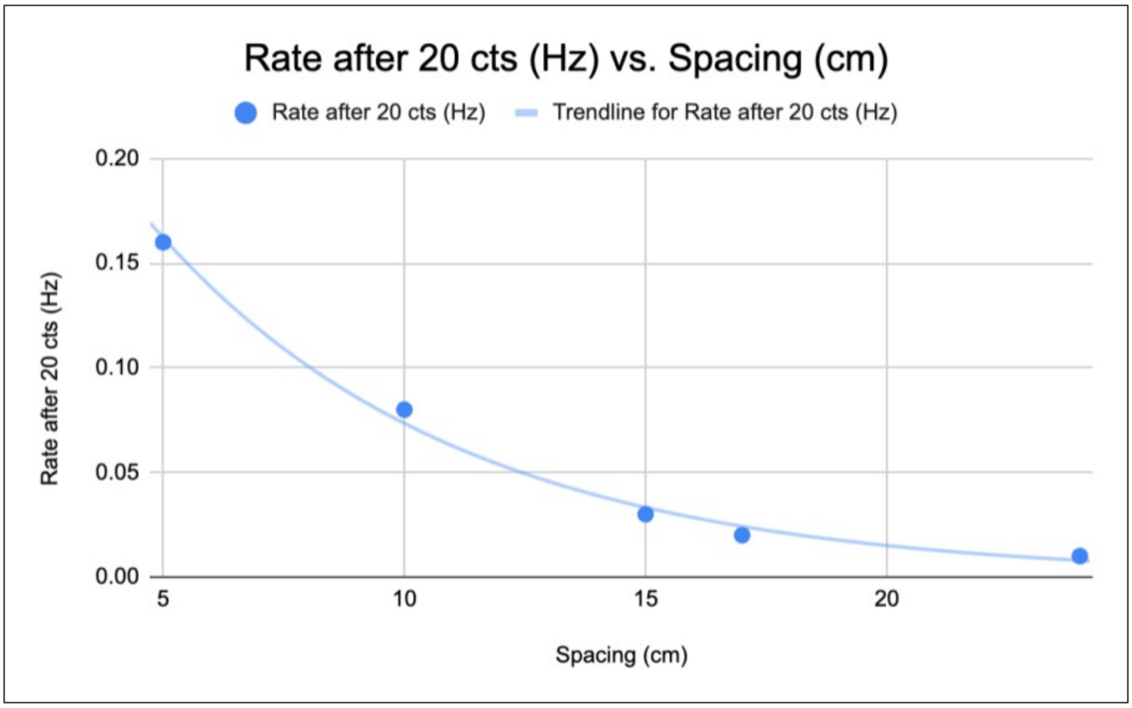

Figure 3. Result of vertical separation experiment.

The vertical separation experiment is useful for both physics and mathematics classes in that it show that the acceptance of cosmic rays depends on solid angles and makes a good exponential fit.

1.2.4 Other experiments

The authors have either attempted or are planning several more experiments suitable for physics classes. The students made measurements of the cosmic ray rate at different floors in two buildings on the Notre Dame campus. The results in one building were inconclusive in preliminary analysis and the second set of results is not yet analyzed, Because of the already low coincidence rates of the Cosmic Watch, the differences due to absorption by ordinary building materials may be difficult to measure. We will find out. The team is also planning measurement of absorption by one or several blocks of steel. Another experiment that the team will try that might be interesting is for the students to bring Cosmic Watch detectors home for a night, let them run, and return them to school the next day and report the rate as a survey of rates in the geographic area. In this case, the rates of the detectors would be normalized in the classroom beforehand to one "master" set that stays in the school.

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2.1 Conclusion

The Cosmic Watch is a viable instrument for practical experiments in a whole-class setting in high school physics. Experimentation at the University of Notre Dame QuarkNet Center has shown that there are several ways of using the Cosmic Watch detectors to introduce cosmic ray physics to students as well as to engage them in physical thinking. It also gives them the chance to measure elementary particles – muons – and their behavior.

Additional work is needed to optimize robustness and reliability of the Cosmic Watch so teachers can take out class sets for a week or two and be assured that students can use them to make reliable measurements. Student and teachers will find more ways to make studies using the Cosmic Watch.

2.2 Acknowledgements

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