Helping Develop America's Technological Workforce

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Cosmic Rays and the Eclipse

Does the Rates of Cosmic Rays change during the 2017 Total Solar Eclipse?

QuarkNet High schools design and carry out cosmic ray experiment across the US

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Fermilab and

University of Illinois at Chicago

Supported by NSF; Fermilab

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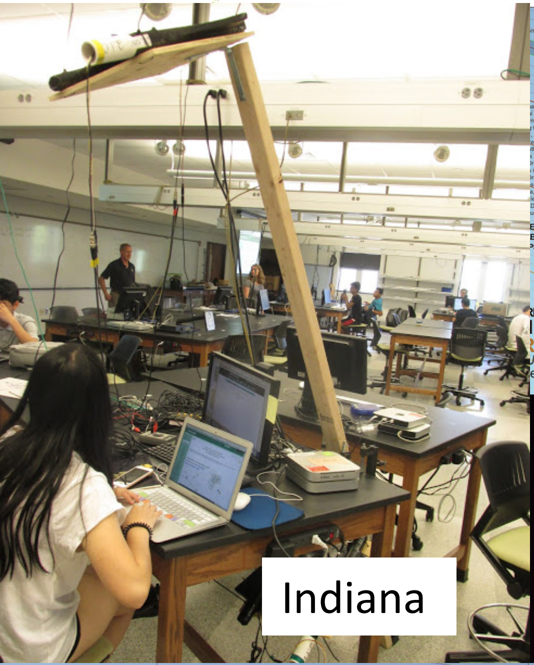
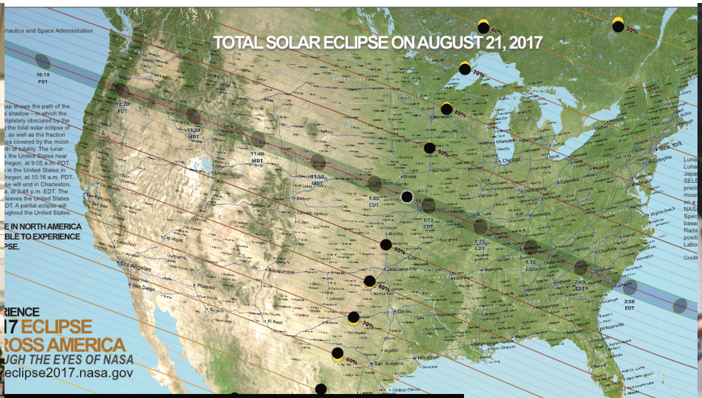
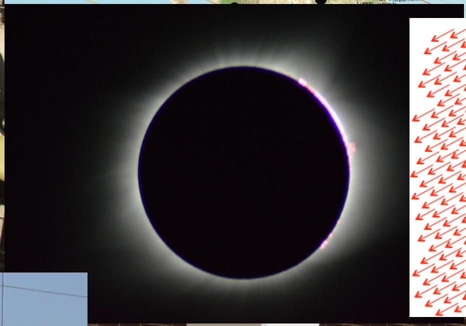
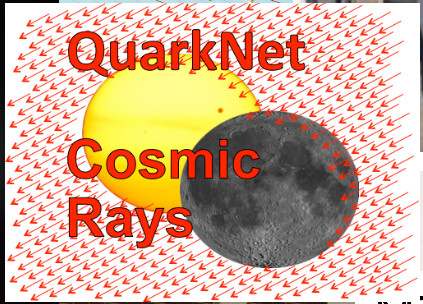
Measuring Cosmic Rays during 2017 Total solar Eclipse









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Outline

- Description of QuarkNet and Cosmic Ray Eclipse Project
- Never been done before with muons at the Earth's surface!
- Develop technique with student-teachers in UIC QuarkNet Center
- Design and build inexpensive prototypes; perform final tests at summer workshops
- Data collection
- Data analysis and Results

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Why can these high schools carry this out?

QuarkNet is an educational outreach effort to high schools consisting of 50 High Energy Physics university groups around the US

Focus is teacher development and research experience

e-Lab website quarknet.org provides access to:

- CERN LHC data
- Fermilab Experiments
- Cosmic Ray detectors and analysis tools – high schools have detectors - 4 scintillation counters and readout!

Nature provided an on-off switch (Eclipse) to any cosmic rays from the sun. Let's exploit it.

High School collaboration built!

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Eclipse Participation

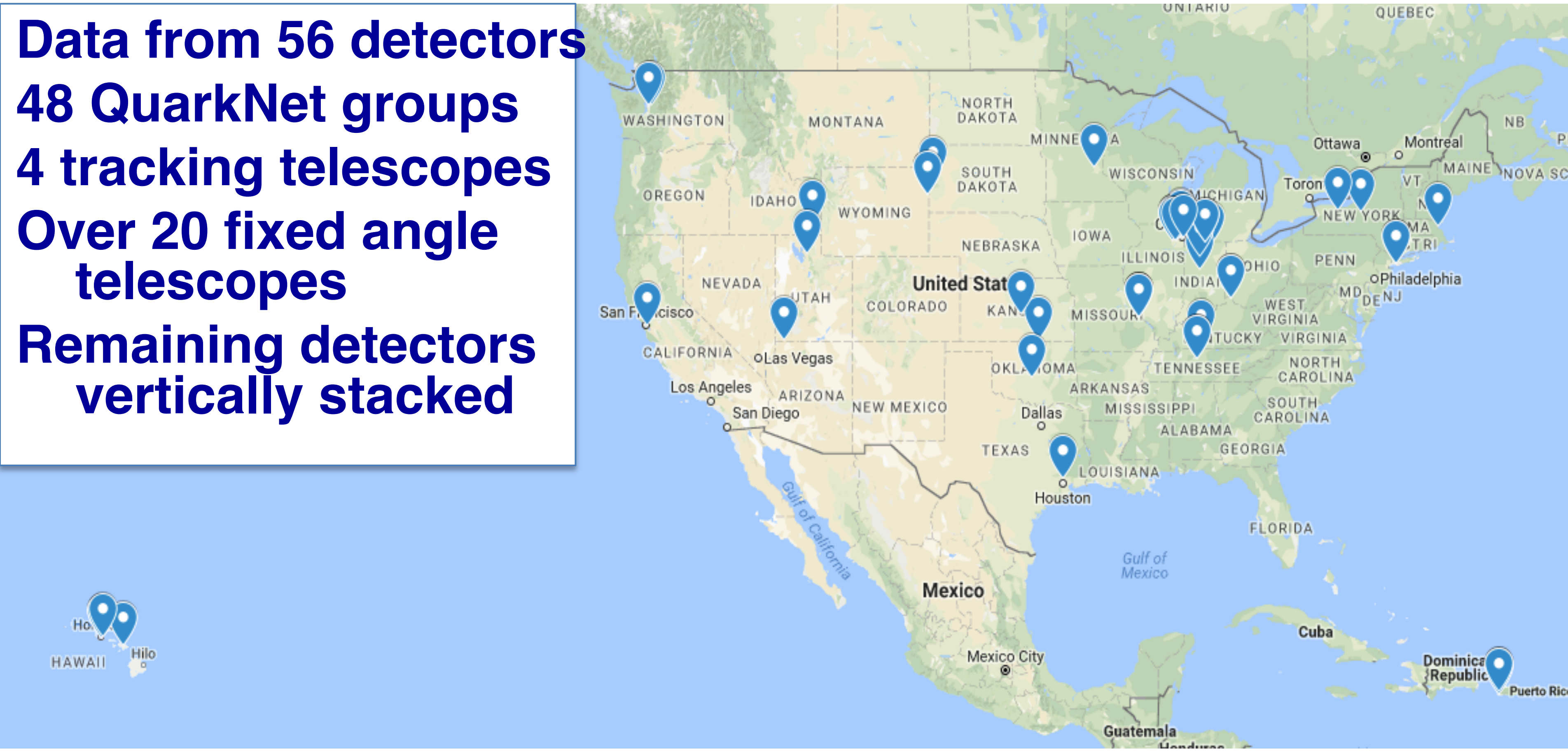
Data from 56 detectors

48 QuarkNet groups

4 tracking telescopes

Over 20 fixed angle telescopes

Remaining detectors vertically stacked



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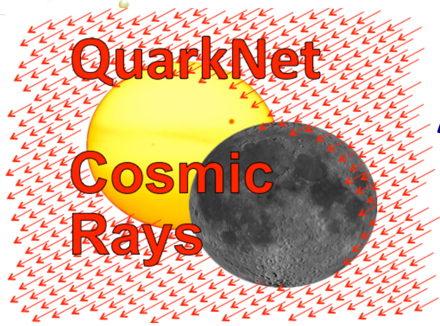
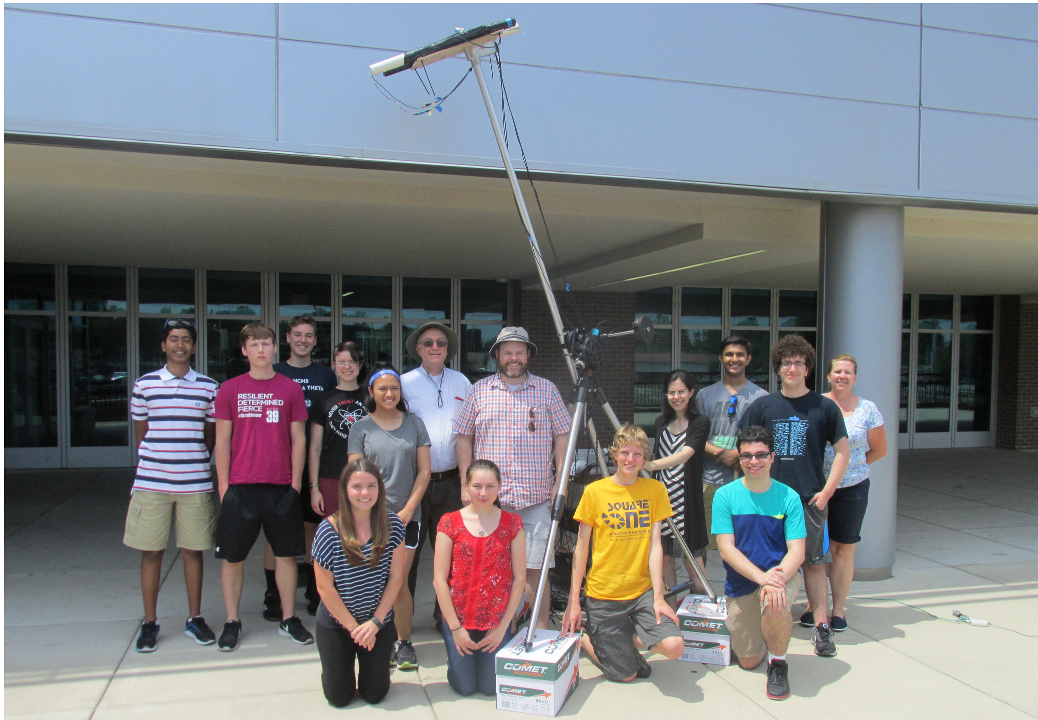
Solar Eclipse Goals



Measure cosmic ray rates near the sun during the August 21st solar eclipse.

- Compare eclipse muon rates to rates when there is empty sky, moon only and sun only
- Show sun is not a major source of cosmic rays; generate limit
- Search for global changes in muon rates



Build telescope from QuarkNet cosmic ray detectors

Cosmic Ray Eclipse Project timeline

- Feb - Idea originated with QuarkNet teacher Nate Unterman at APS conference. Brand new research question! No previous publications on surface muons during an eclipse exist.
- 6 months to assemble collaboration of QuarkNet teachers and students
- Create website to host instructions, logbook, collaborator comments
- Summer - assemble prototypes during workshops
- August 21 – Eclipse data taking
- Sept-Dec – Analysis of independent sites

Found one non-directional result this month

Title: Measurements of Cosmic Rays during the Solar Eclipse of June 19 1936
Authors: Nishina, Y., Ishii, C., Asano, Y., & Sekido, Y.
Journal: Japanese Journal of Astronomy and Geophysics, Vol. 14, p.265

No difference observed during eclipse using an electroscope. < 0.75% of muon flux.

"thanks to Professor Robert A. Millikan and Dr. H. Victor Neher for the construction of the Neher electroscope"

The QuarkNet experiment improves this limit by a factor ~ 80

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Design and Prototypes

Built on previous QuarkNet attempts to measure muon shadow caused by sun

Muons in direction of sun vs 30-minute bins, 45 days (2016) - 0.8% effect using telescope with 2.5 degree acceptance.   Too small to measure in 90 minutes.

- Three telescope designs: tracker to follow sun; fixed-angle to let sun move across acceptance; normal stack for full sky
- All high school groups can contribute – use existing detectors and new frames.   Expand on International Cosmic Day (DESY) and International Muon Week (QuarkNet) participation
- Frame for Tracker: cheap; light; parts available at local hardware stores; support with telescope mount

QuarkNet Student-designed Prototypes

Design Challenges:

Muon rates versus pointing resolution

Overlap/separation of counter pairs

Normalization with pairs to avoid pressure effect

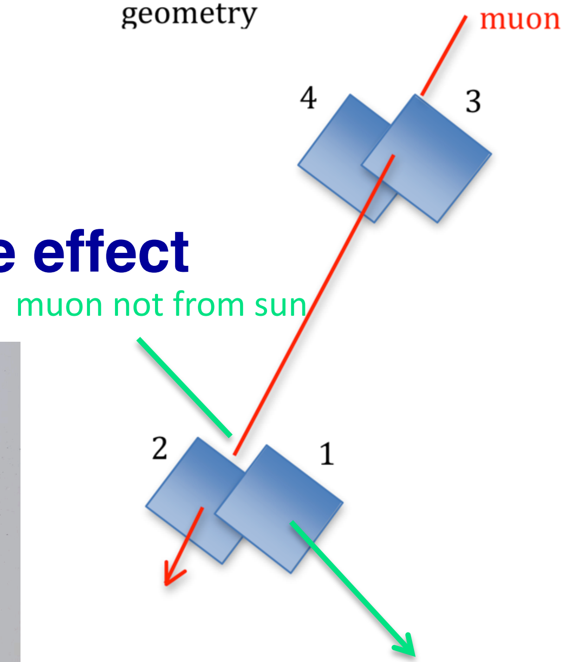
Rate ~ $\cos^2(\theta)$

Constructed telescope frames for Tracking and Fixed telescopes

Use 2-fold triggering

Invite other schools for summer?

East-West fixed-angle geometry



Fixed-Angle Telescope

Measured muon rates to identify optimum separation: resolution vs rates (statistical sensitivity)

(10 feet for Tracking and 6 feet for Fixed Telescopes)

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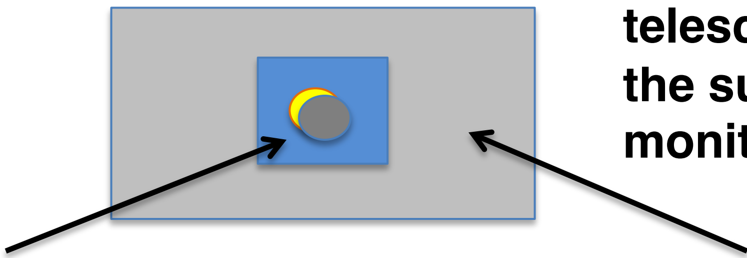
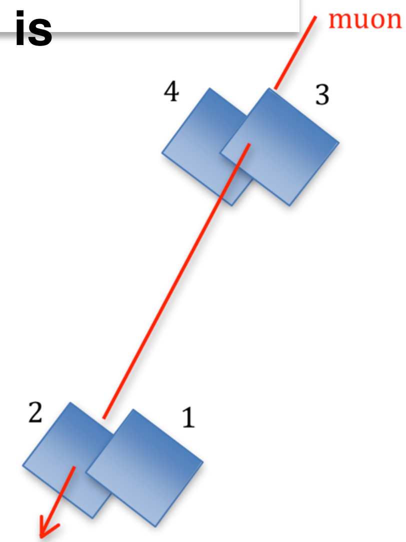
Tracking Detector

Using a shadow of a target on the frame, the telescope is adjusted to follow the position of the sun. The region around the sun is monitored continuously.



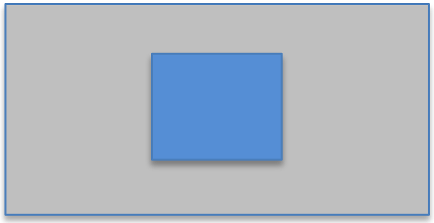


Muons traversing all 4 counters come from the blue region

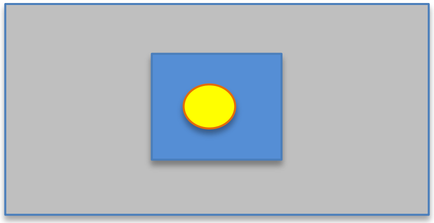
Muons traversing one counter from each end come from the gray region

Compare muon rates during eclipse above to rates under conditions below

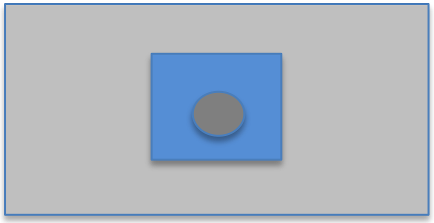
Empty Sky



Sun only in Sky



Moon only in Sky



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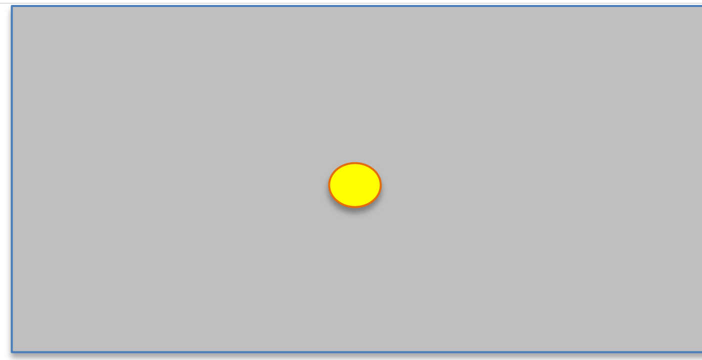
QuarkNet Telescopes

Fixed-Angle

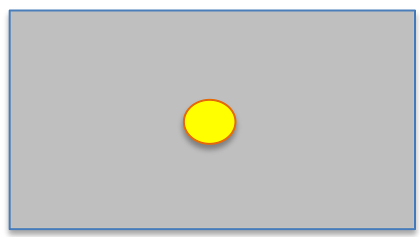
- Wide angle view
- Higher rates
- Low signal-to-noise



The gray area is the acceptance of the telescope – the part of the sky that muons come from that can trigger the detector

Tracking

- Narrow angle view
- Lower rates
- Better signal-to-noise



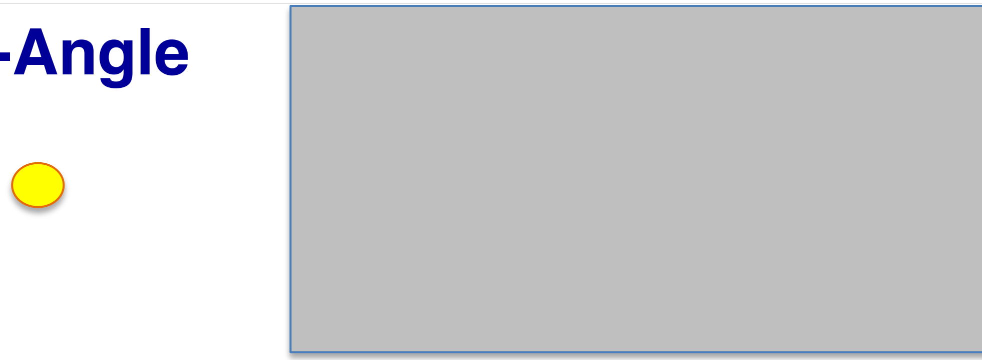
Hard to build; aim every 3 minutes

Don't know what an eclipse signal looks like. Measure at different angular scales

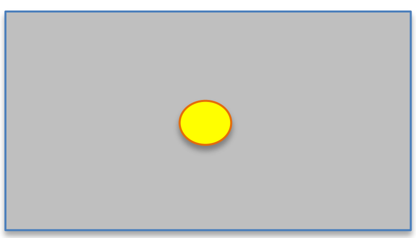
Next 5 slides show relative positions of telescopes and sun every 30 minutes

QuarkNet Telescopes

Fixed-Angle

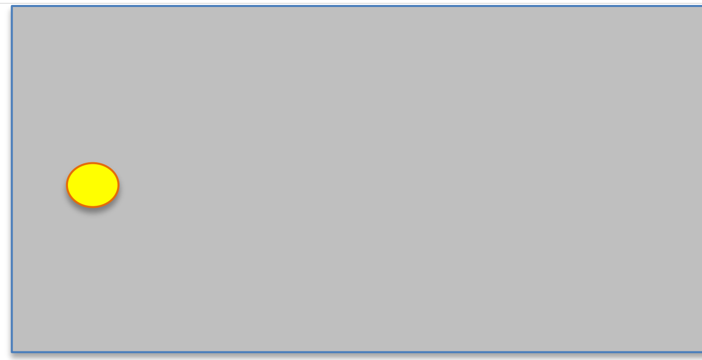


Tracking

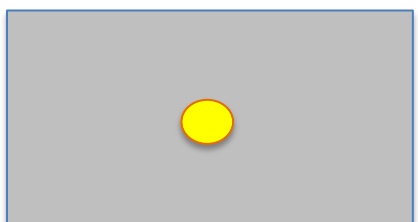


QuarkNet Telescopes

Fixed-Angle

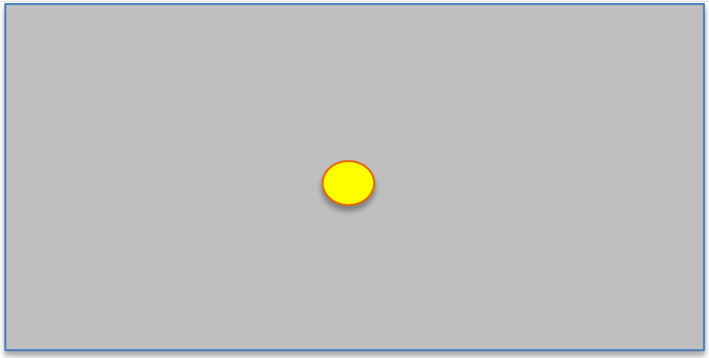


Tracking

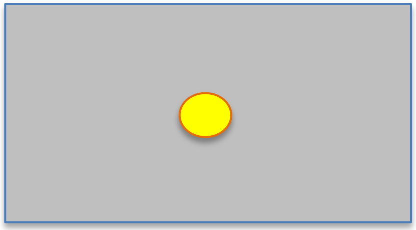


QuarkNet Telescopes

Fixed-Angle



Tracking



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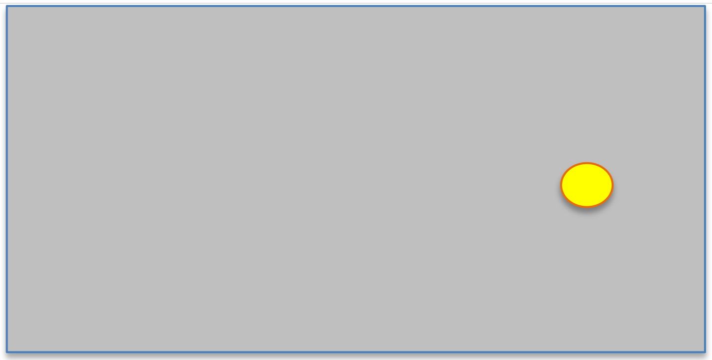
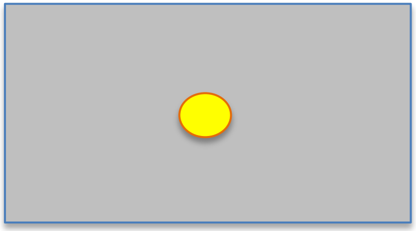
Fixed-Angle



Tracking



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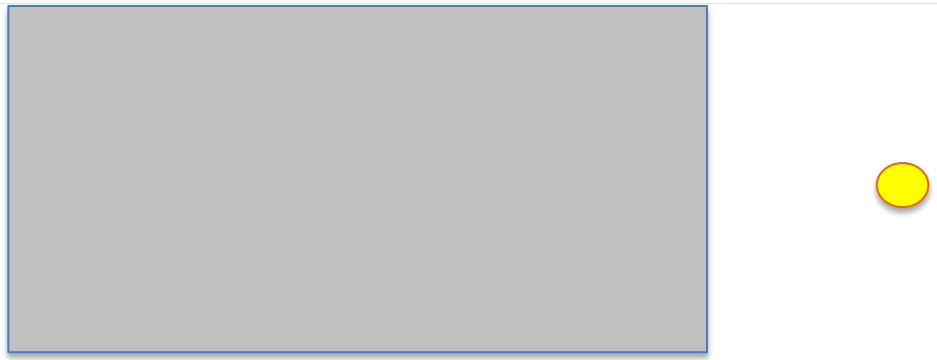
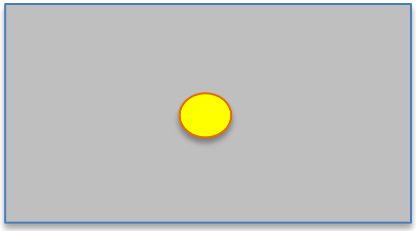
Fixed-Angle



Tracking



Eclipse lasted ~ 2 hours. Our slides covered 2.5 hours

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Typical Rates

	Expected Muon Rates	counts 10-minute bin
Stack	5 per second	3000
Fixed-Angle	15 per minute	150
Tracking		
parallel pairs	5 per minute	50
(3 degree overlap)	0.3 per minute	3
Muon rate in 0.5 degrees (size of sun)		0.1

Eclipse expectation

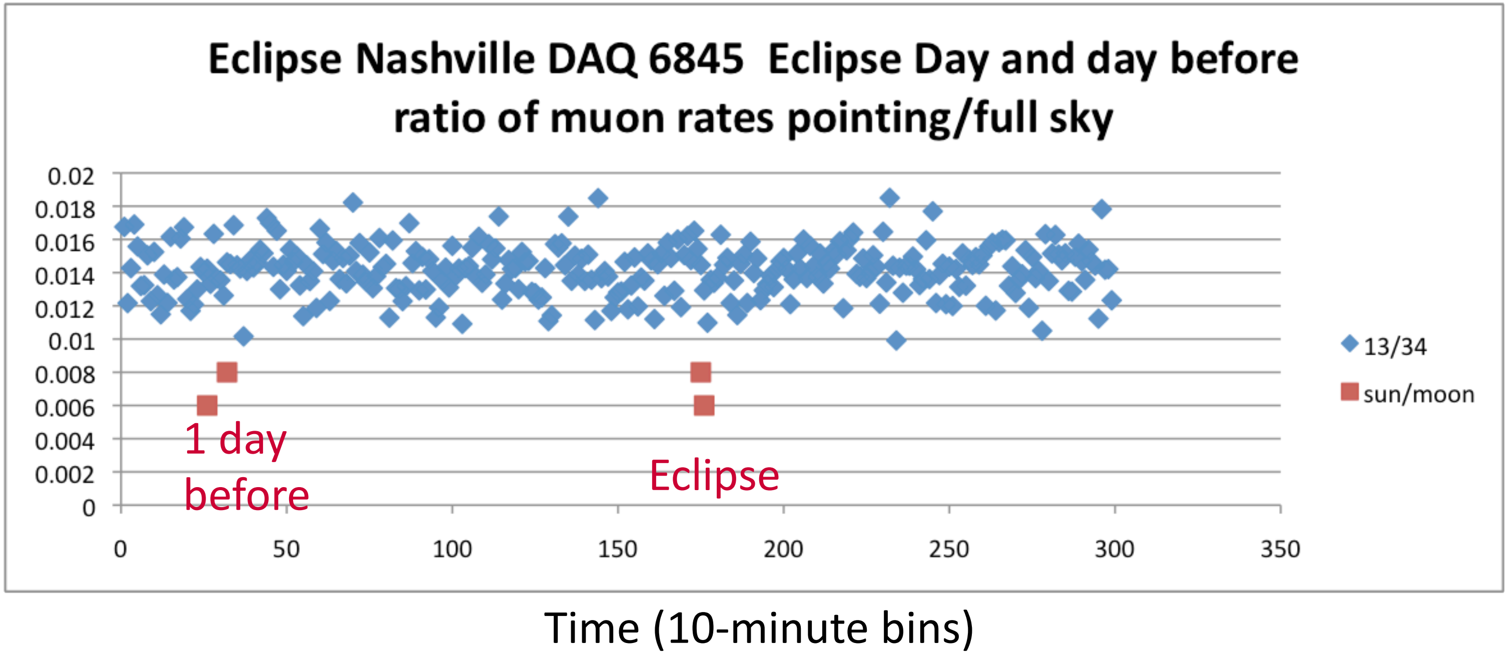
- 10% errors in 10-minute bins; 4% errors over full eclipse
- combining various sites improves sensitivity

Eclipse Analysis

- Students have measured muon rates versus time –all conditions
- Normalization techniques used to reduce effects due to changes in atmospheric pressure
- Counter pairs from normalization also identify periods when counters were working stably
- Identified problems – due to intense heat buildup from sun. Counters were wrapped in dark bags
- (counters disconnected from scintillator and flakey connections had to be repaired)
- Future – combine more results from sites around US.

QuarkNet Fixed-Angle Results Example

Nashville data – muon rate pointing toward the sun divided by the muon rate from the full sky



No signal change during period that sun passes through acceptance - day before or eclipse.

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Limits from Fixed -Angle

No difference in Nashville data observed at the 4% level of muons pointing near the sun

Condition	Ratio pointing to sun/full sky (%)
Empty Sky	1.42 +- 0.01
Moon only	1.38 +- 0.05
Sun Only	1.44 +- 0.05
Eclipse 4% statistical error	1.42 +- 0.05

Stacked arrays observe 5x muon rate of telescope's "full sky".

Combining data from 5 sites: R (eclipse/empty) = 0.998+-0.018

95% CL Limit = 1×10^{-4} of muons come from the sun

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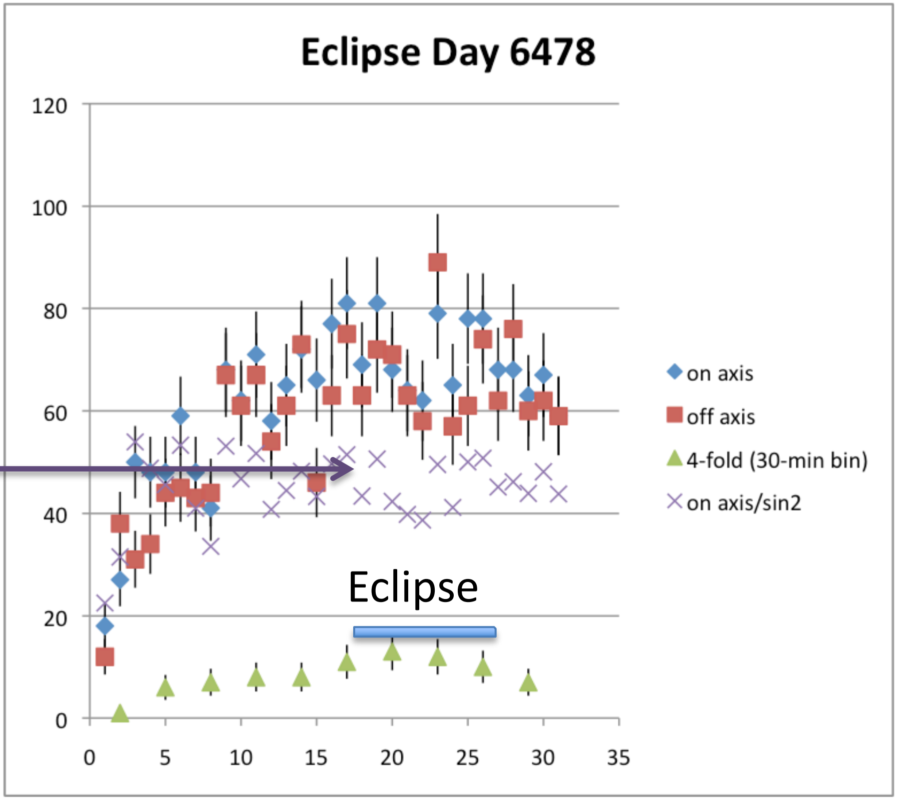
Results – Tracking Telescope

On-axis and off-axis rates during Eclipse change versus zenith angle



On-axis weighted by $\cos^2(\theta)$

Eclipse 45.2+-1.8

Wings 46.4+-1.6

No Difference

Look carefully at backgrounds

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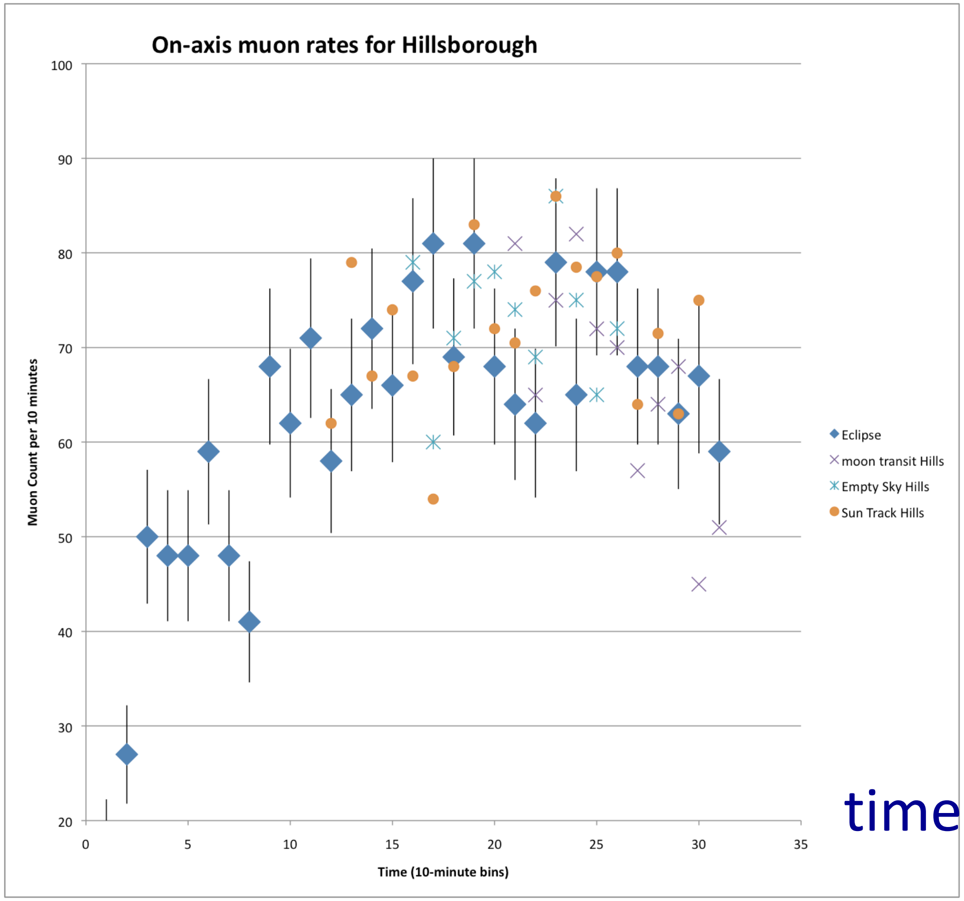
Tracking Results

On-Axis muon rates eclipse; moon; sun; empty sky

Eclipse and background shapes similar

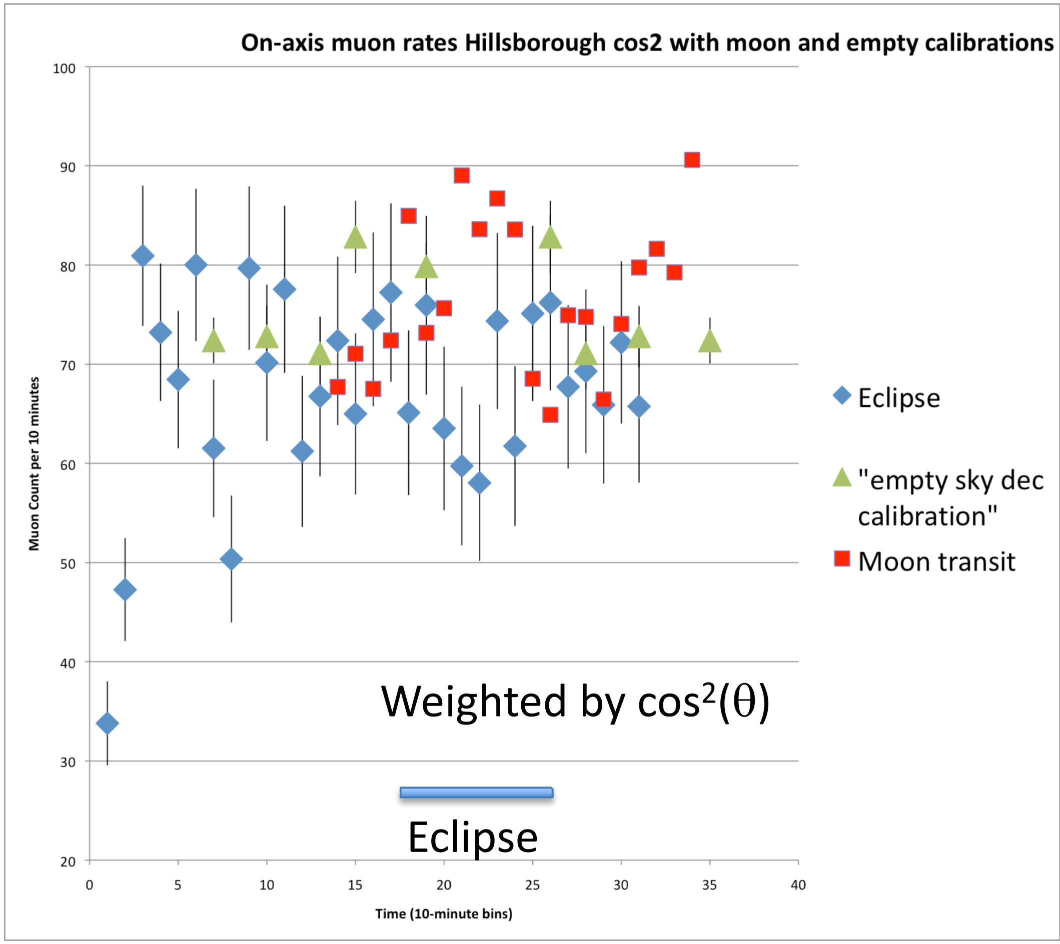


QuarkNet More Background Calibration

Collect calibration data for empty sky and longer moon transit to attempt to improve errors on backgrounds

Weight by $\cos^2(\theta)$

Drop in rates at Eclipse not significant. Systematic errors not well enough understood to calculate a limit yet.



Future: teachers can improve limits

Combine analyses from all QuarkNet groups with telescopes active during the eclipse

Produce a 90% confidence limit for changes during the eclipse for all three telescope types: fixed, tracking, stack. Publish the full US result.

Some groups plan to measure the shadow that the sun and moon cast in the cosmic ray flux; and correlate muon rates with solar activity

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Summary

- High schools around the US combined to carry out original research with QuarkNet cosmic ray detectors during the 2017 total solar eclipse
- Teachers and students assembled a large collaboration Analysis tools and detectors developed
- Prototypes constructed
- Collected data - during summer break!
- Observed the total solar eclipse
- Preliminary analysis presented from a subset of sites – Limit < 1×10^{-4} of muons come from sun - more analysis possible