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Cosmic Rays and the Eclipse

Hypothesis: Rates of Cosmic Rays will change during the 2017 Total Solar Eclipse

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

Mark Adams

QuarkNet Cosmic Ray Coordinator

Fermilab and

University of Illinois at Chicago

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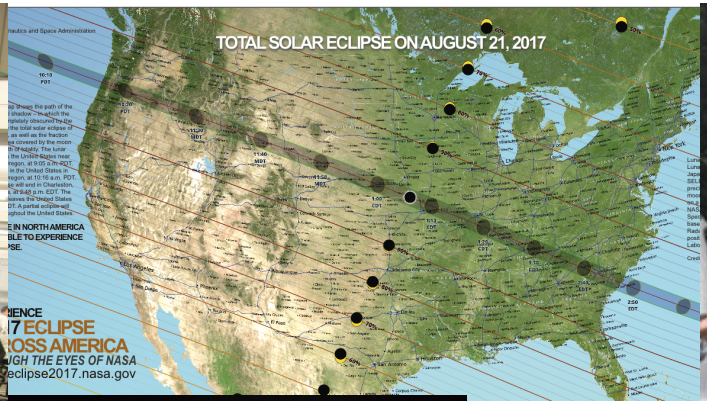
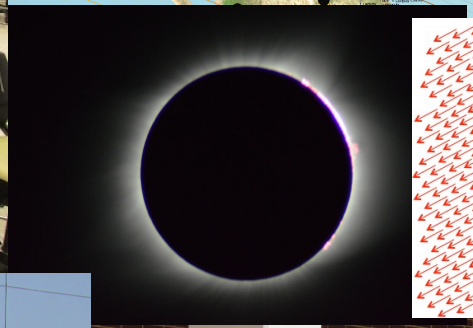
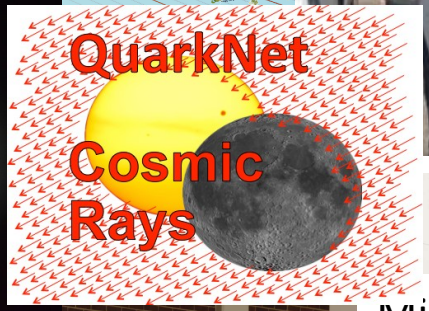
Measuring Cosmic Rays during 2017 Total solar Eclipse

Indiana







Mississippi

Illinois

Missouri

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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 Center
- Design and build inexpensive prototypes; perform final tests at summer workshops
- Data collection
- Data analysis and Results
- Future
- Students have presented results at earlier sessions and they are here to answer your questions during

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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 already have detectors- 4 scintillation counters!

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

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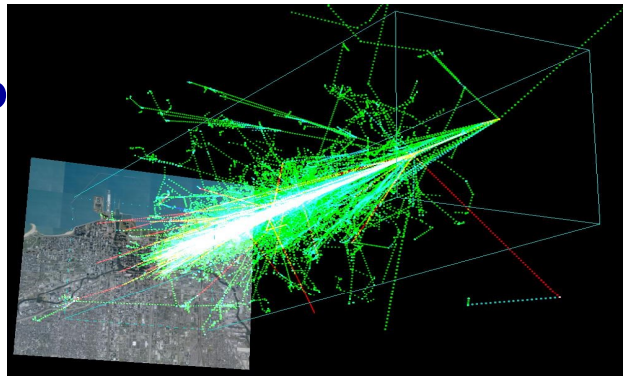
Cosmic Rays

Cosmic Rays are high energy particles that originate from exploding stars

Hit upper atmosphere; cause HEP shower into many particles



Muons are the sole charged survivors at the earth's surface

Muons have energies > 3 GeV [3,000,000,000 more energy per particle than the visible light output from the sun]

Expect no CR signal from the sun – but the eclipse let's us search for CRs with great sensitivity. Measure

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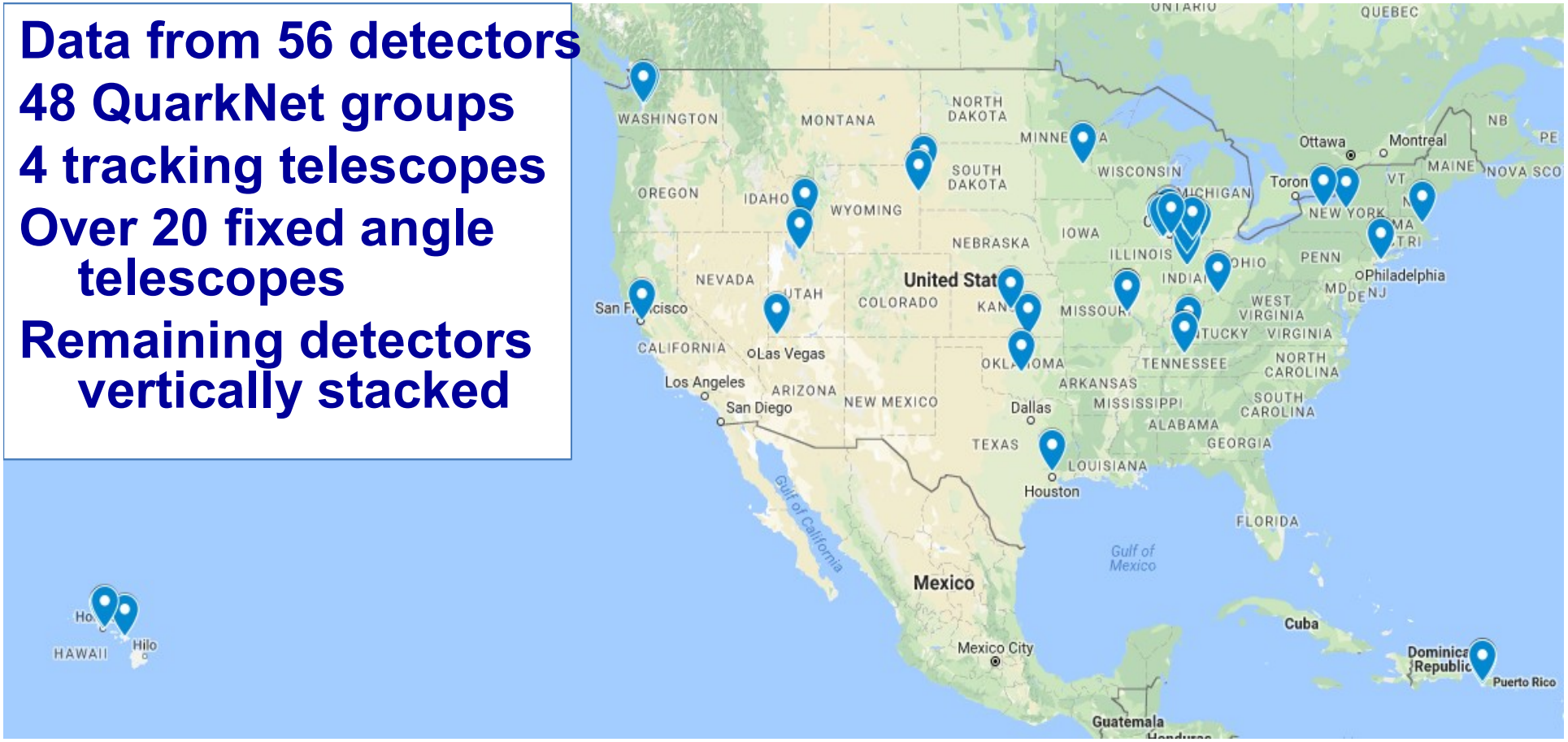
Eclipse Participation

- Data from 56 detectors
- 48 QuarkNet groups
- 4 tracking telescopes
- Over 20 fixed angle telescopes
- Remaining detectors vertically stacked



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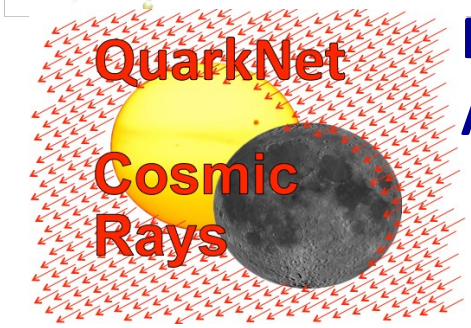
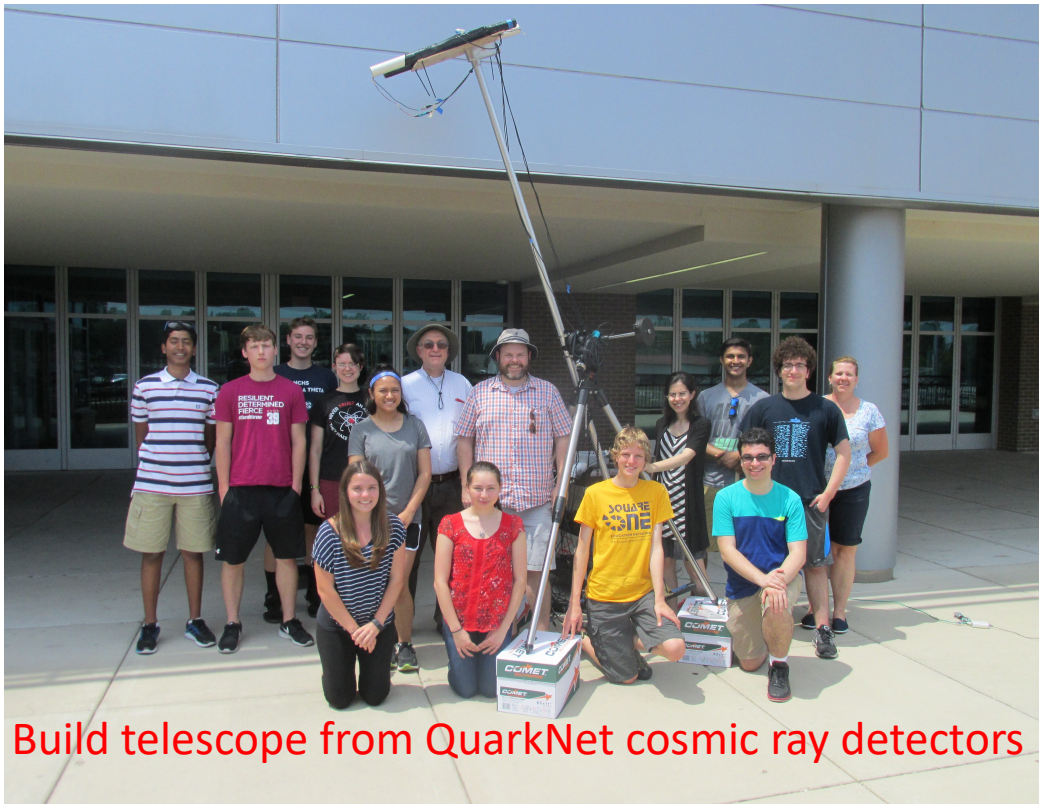
Solar Eclipse Goals



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**
- **Search for global changes in muon rates**
- **Over 45 groups**


Build telescope from QuarkNet cosmic ray detectors

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Cosmic Ray Eclipse Project 2017 timeline

- Feb - Idea originated with QuarkNet teacher Nate Unterman at AAPT 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
- Spring - high schools design measurement goals and techniques. Invite other QuarkNet participants
- Create website to host instructions, logbook, collaborator comments
- Summer - assemble prototypes during workshops
- August 21 – Eclipse data taking
- Sept-Dec – Analysis of independent sites; first combination
- Jan. 2018 - Announce results

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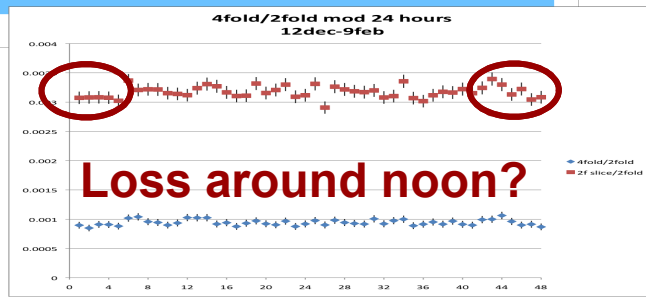
Design and Prototypes



Build on previous QuarkNet attempts to measure muon shadow caused by Sun

Muons in direction of sun vs 30-minute bins, 45 days overlapped (2016). 8% effect in 2.5 degree acceptance.

Will any effect be 0.5 degrees (moon size) or wider due to earth's magnetic field?

All high school groups can contribute – use existing detectors and design telescope frames. Expand on International Cosmic Day and International Muon Week participation

Three telescope designs: tracker to follow sun; fixed-angle to let sun move across acceptance; normal stack for full sky

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 of counter pairs; Separation of counte

Normalization with pairs to avoid 1/pressure ef

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

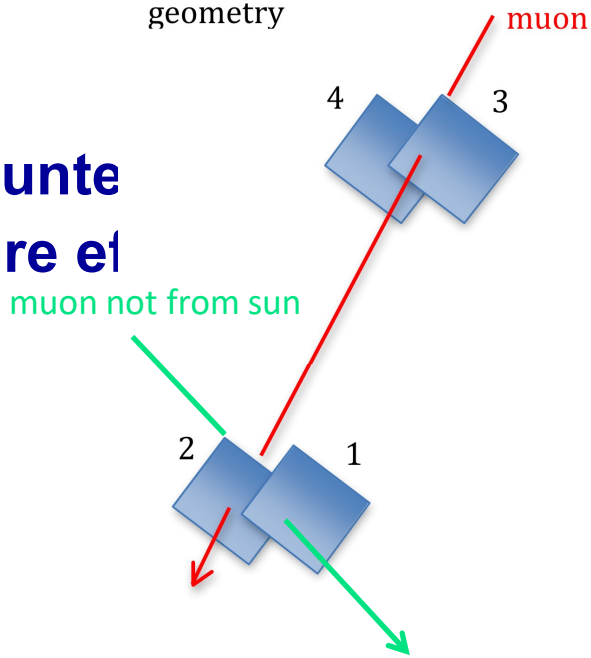
Constructed telescope

frames for Tracking and

Fixed telescopes

Use 2-fold triggering

East-West fixed-angle geometry



Fixed-Angle Telescope

Will other schools participate during summer?

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

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

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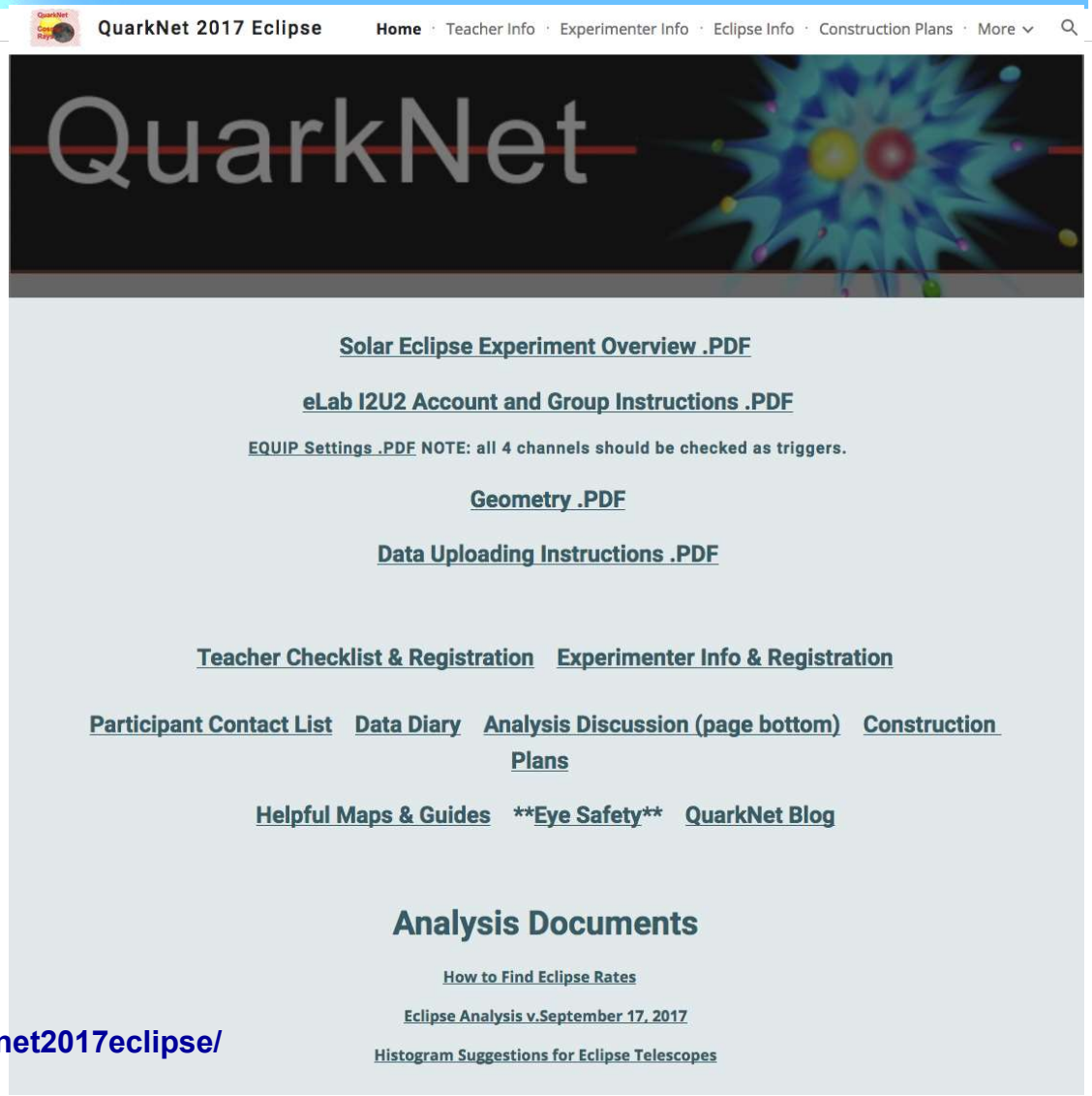
Create Central Logbook

Communication Required!

- **Eclipse website:**
- **Goals**
- **Instructions**
- **Collaborator information**
- **Eclipse maps and info**
- **Analysis tools and examples**
- **Logbook for data sets**



https://sites.google.com/view/quarknet2017eclipse/

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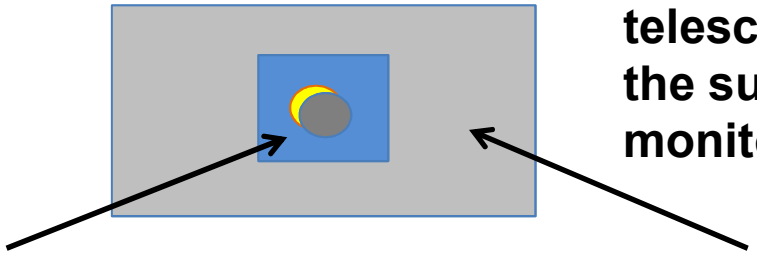
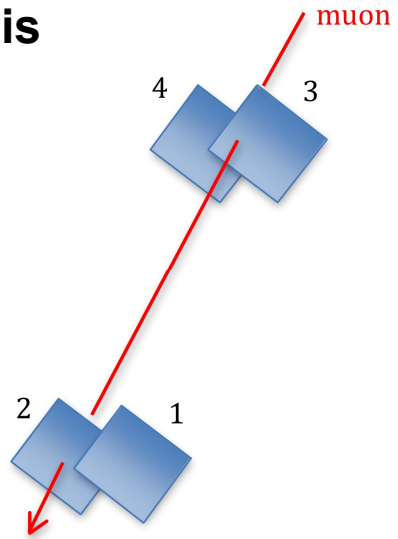
Tracking Detector



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.

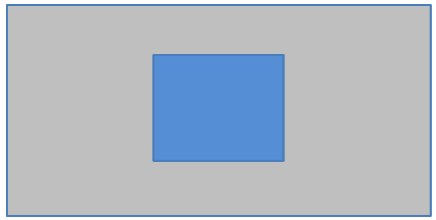


Muons traversing all 4 counters come from the blue region

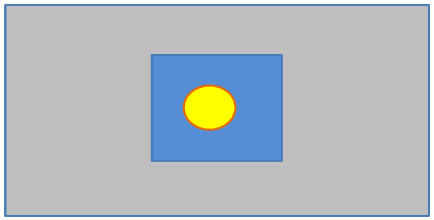
Muons traversing one counter from each end come from the gray region

Compare muon rates during eclipse above to rates under conditions below

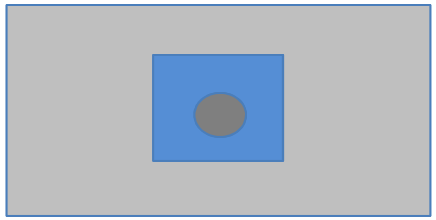
Empty Sky



Sun only in Sky



Moon only in Sky



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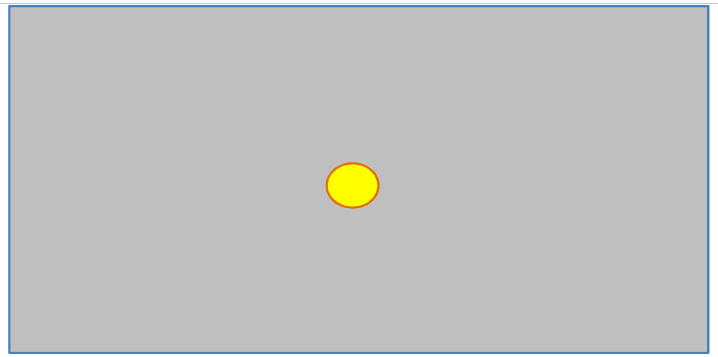
QuarkNet Telescopes

Fixed-Angle

Wide angle view

Higher rates

Low signal-to-noise



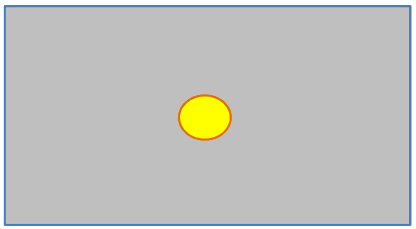
The gray area is the acceptance of the telescope – the part of the sky that muons come from that can trigger the detector

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

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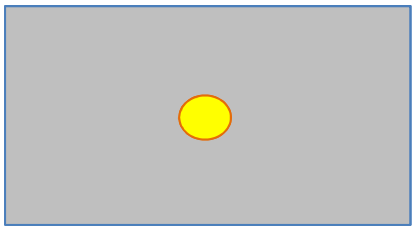
Fixed-Angle

Tracking



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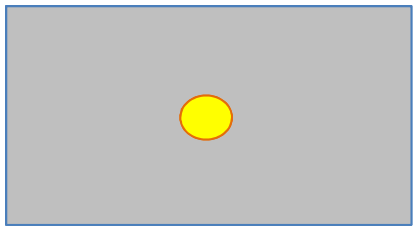
Fixed-Angle

Tracking



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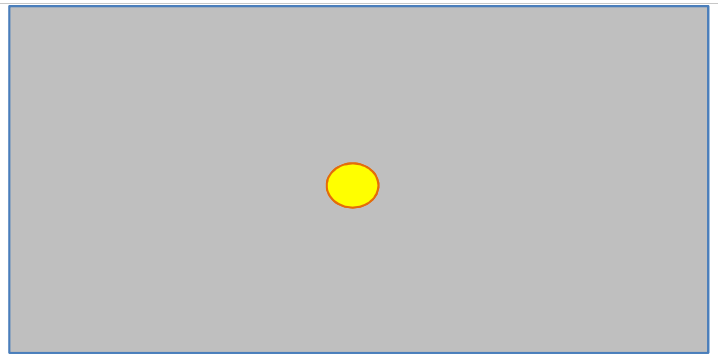
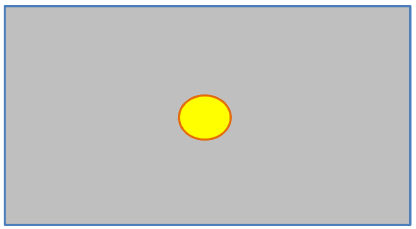
Fixed-Angle



Tracking



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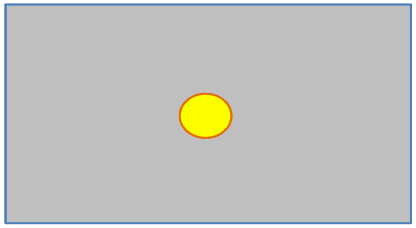
QuarkNet Telescopes

Fixed-Angle

Tracking



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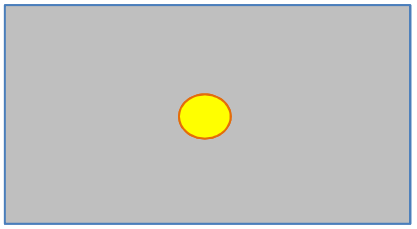
Fixed-Angle

Tracking



Eclipse lasted ~ 2 hours. Our slides covered 2.5 hours

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Typical Rates

Expected Muon Rates

		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; 3% errors over full eclipse
- combining sites will improve sensitivity

Student experimenter preparation

- Informed other QuarkNet participants how to build telescopes
- Measured muon rates during empty sky, sky with moon and sky with sun
- Developed tracking procedures - align with telescope's shadow; laser to transfer position vs time to ground; use laser to reproduce during eclipse if cloudy; realign every 3 minutes
- Measured 2-muon backgrounds to be < 3% of reconstructed in direction of the sun
- 4-day trip to total eclipse location,
  so baselines could be measured
  ahead of the eclipse

- QuarkNet staff developed an e-Lab analysis tool the students requested to measure rates versus time for various combinations of counters

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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 results from sites around the US.

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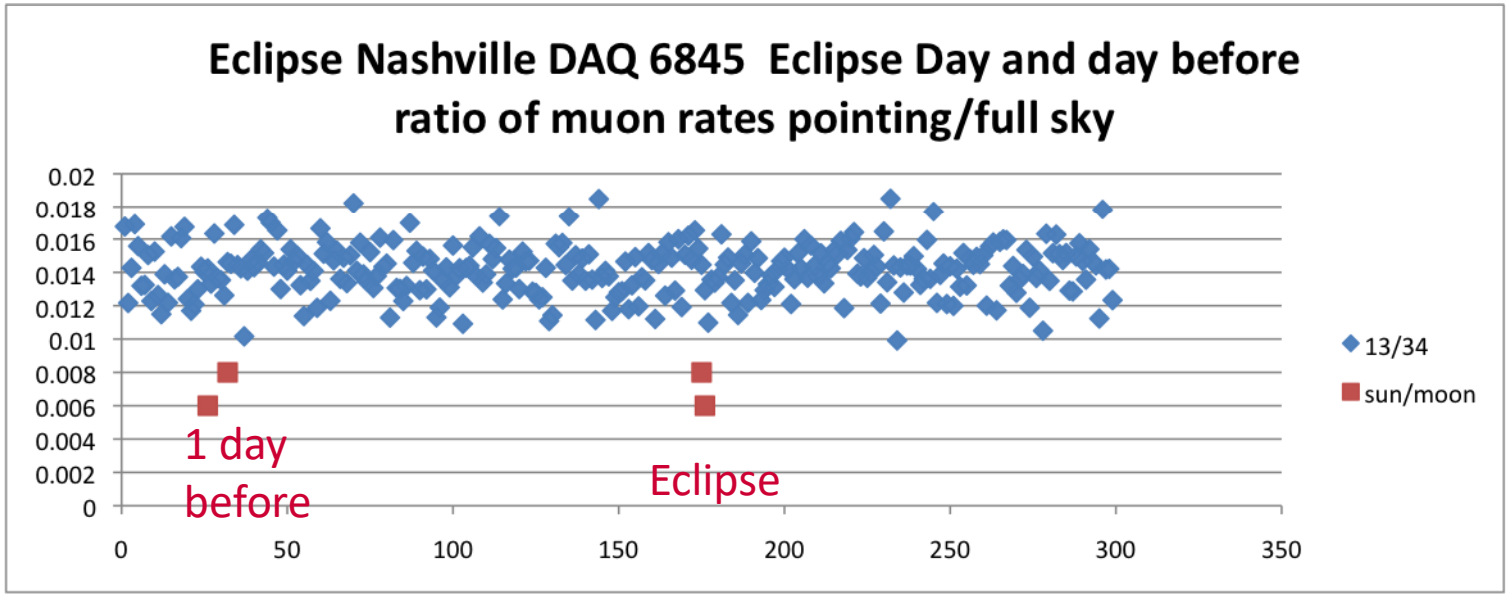
Fixed-Angle Results Example

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



Time (10-minute bins)

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	1.42 +- 0.05 4% statistical error

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

Limit of cosmic rays from sun ~ 8×10^{-5} of all muons

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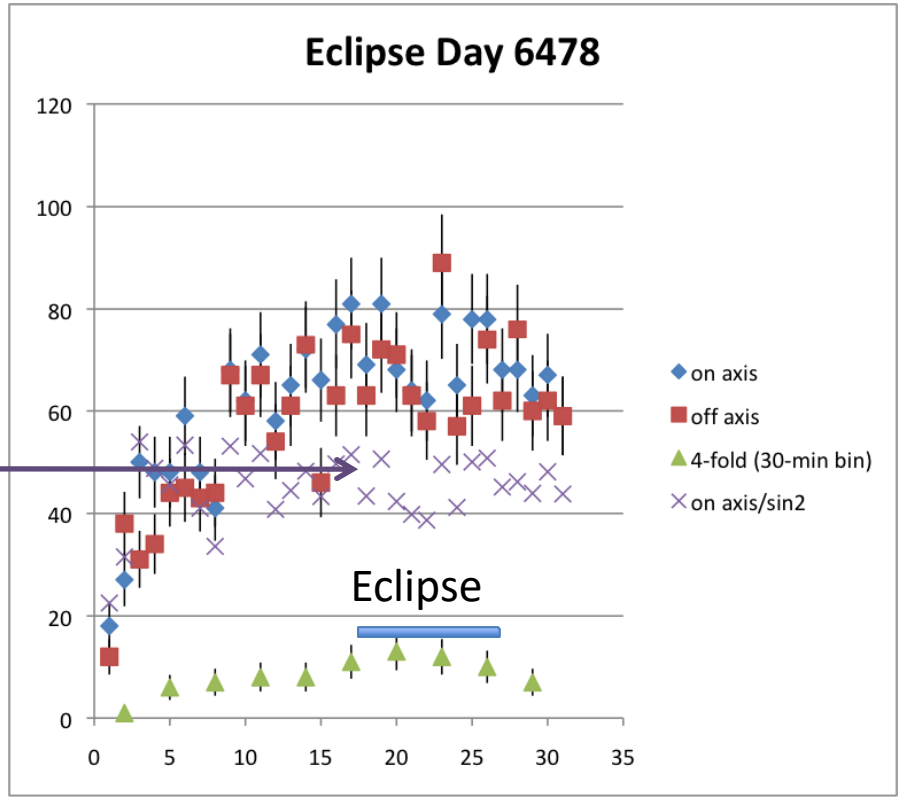
Results – Tracking Telescope

On-axis and off-axis rates during Eclipse

change versus zenith angle



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

Eclipse 45.2+-1.8

Wings 46.4+-1.6

No Difference

Look carefully at

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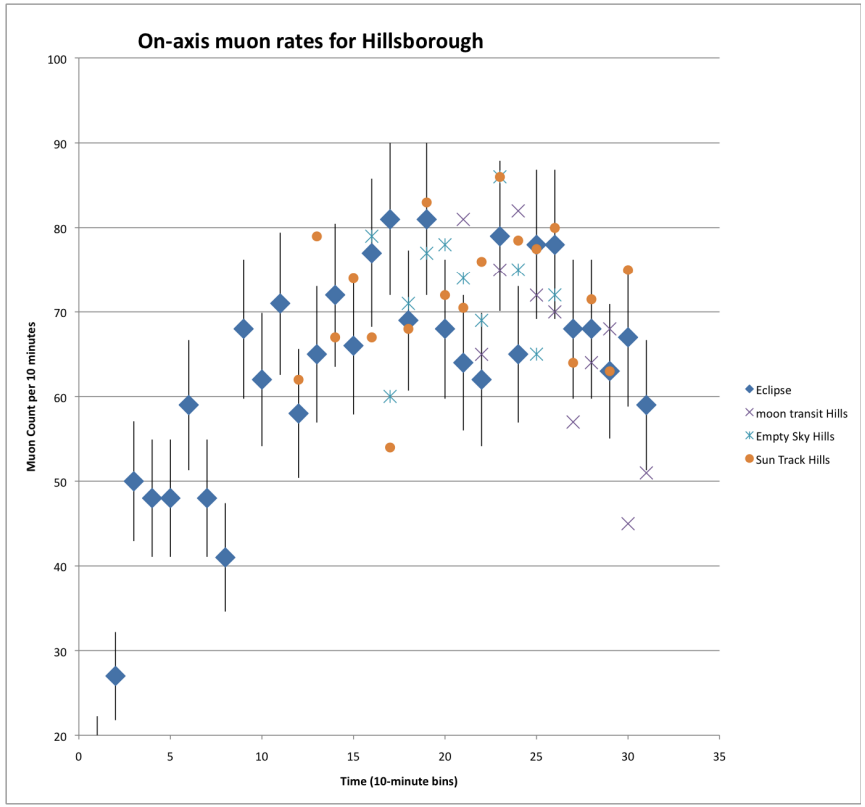
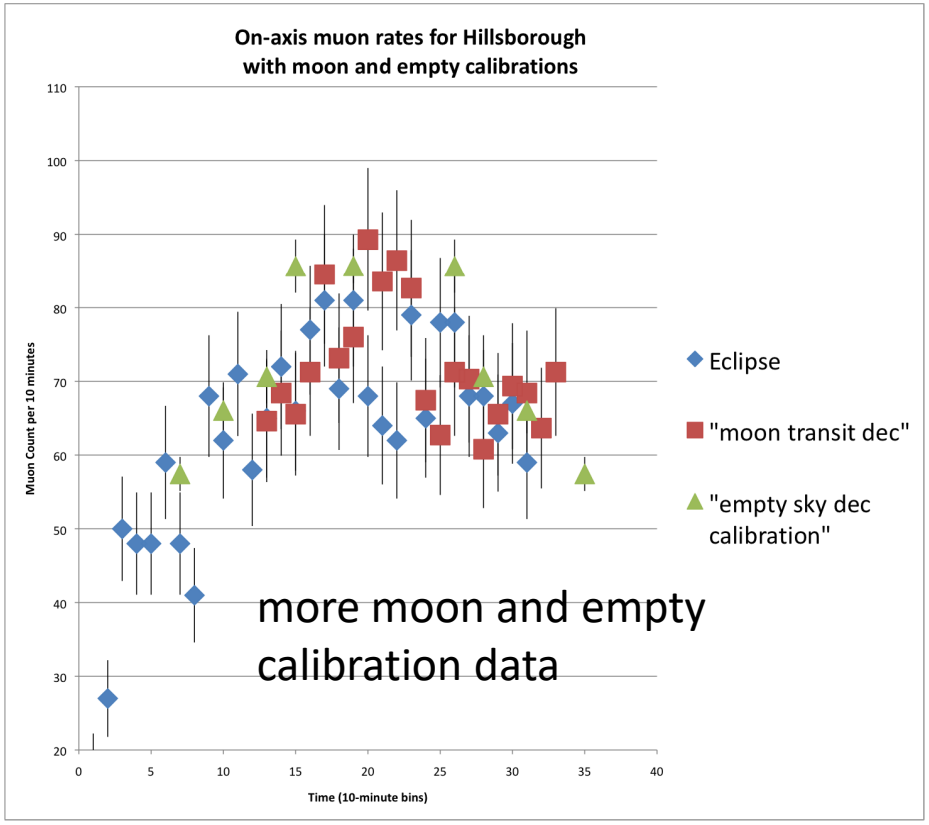
Tracking Results

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





Eclipse and background shapes similar

Does rate in eclipse region drop?

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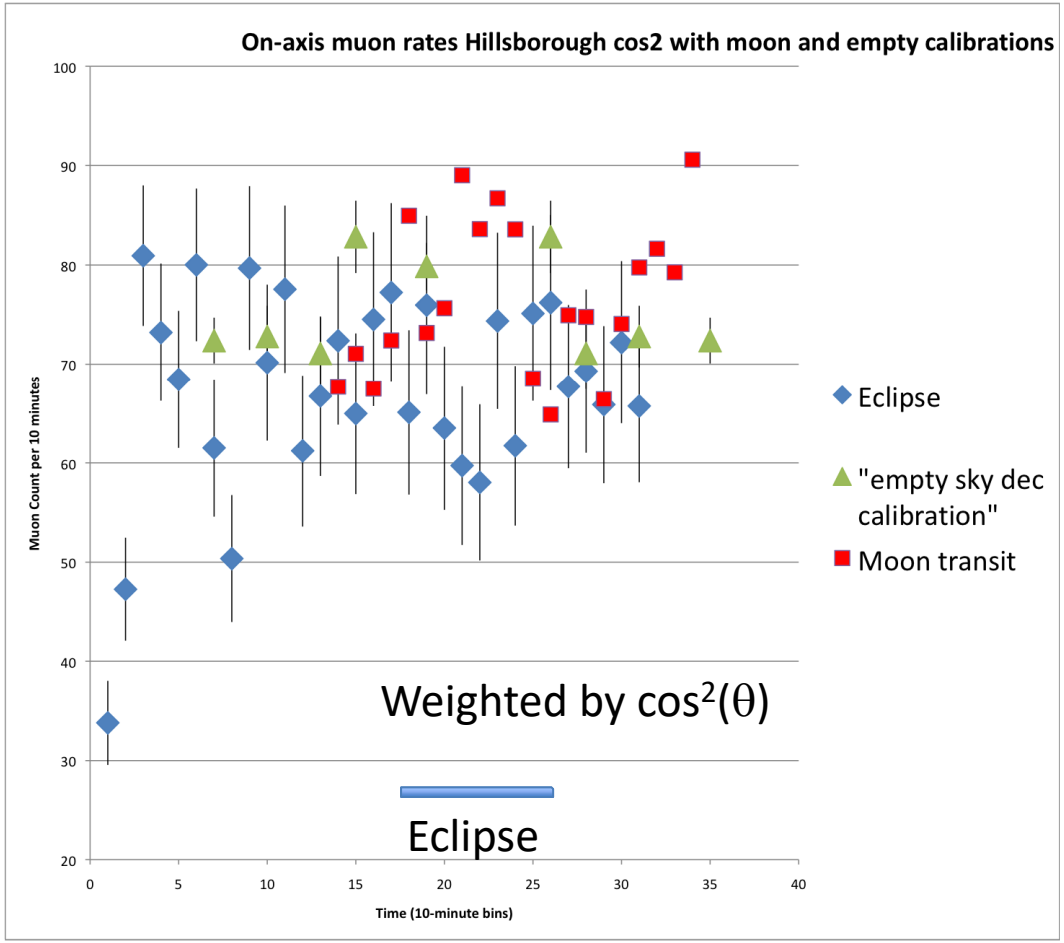
Better Background Calibration

- Collect calibration data for empty sky and longer moon transit to improve errors on backgrounds
- Drop in rates at Eclipse not significant. Will continue to improve upper limits: add 4-fold data and data from multiple telescopes



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Future

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 will attempt 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 at AAPT – more analysis
- If that is not enough - groups now have telescopes and are currently trying to observe the muon deficit around sun and rate changes due to solar activity