Cosmic Ray Studies

2019 International Muon Week

Measure the Speed of Muons

GPS back-to-1999 debacle

Muon Underground Shielding Experiment (MUSE)

QuarkNet high schools proposed cosmic ray measurement in Fermi's MINOS tunnel

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QUARKNET high schools have scintillation detectors

QuarkNet is an educational outreach effort to high schools consisting of 50 high-energy physics university groups around the U.S.

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—four scintillation counters. ~ 200 sites upload data regularly

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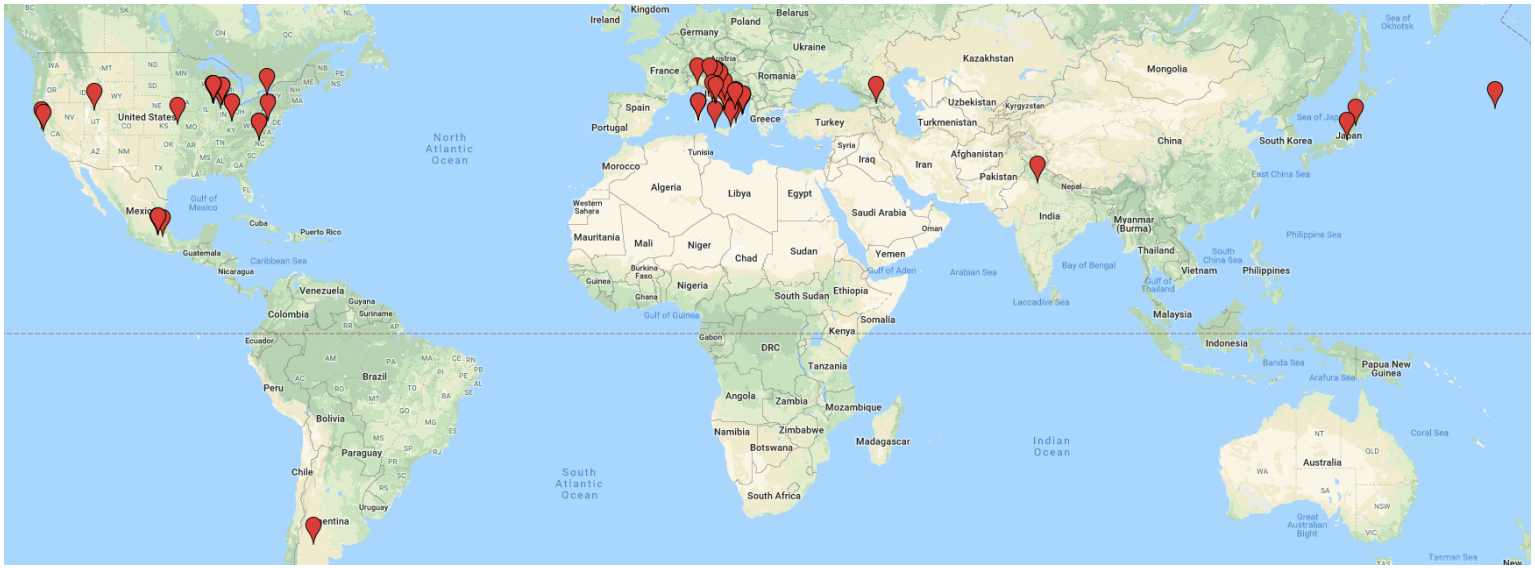
International Muon Week

Operated detectors world-wide during April 1-5; shared data and results.

Theme: Average Speed of Muons

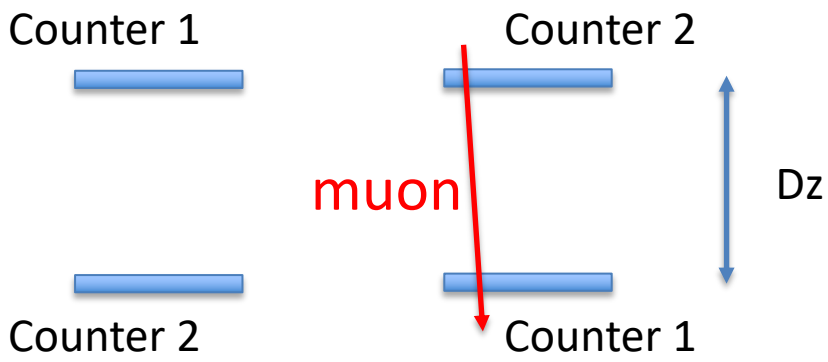
Goal was more international participation -> large EEE effort

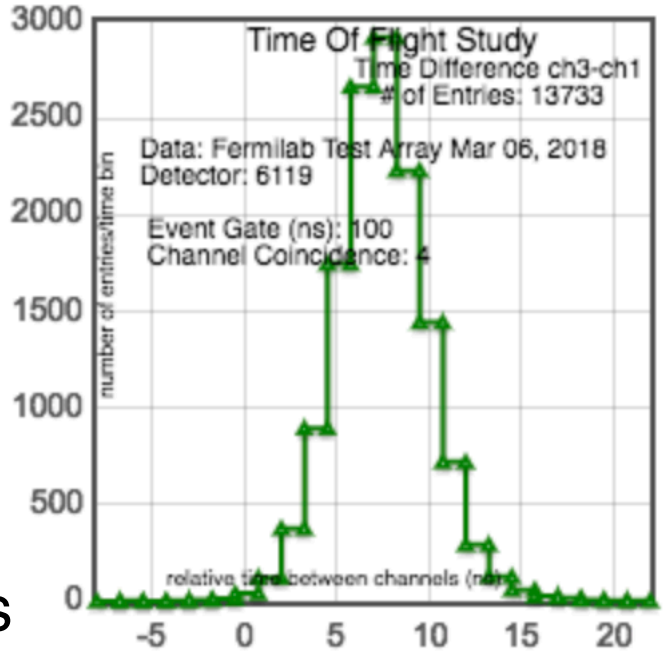


Record 54 sites participated; 19 uploaded results (only 12 sites in 2018)

QuarkNet Speed of Muon

Compare time of flight between two counters in two setups.





Calculate dz/dt; speed = 2.7 x 10^8 m/s

Some groups also searched for upward-going muons.

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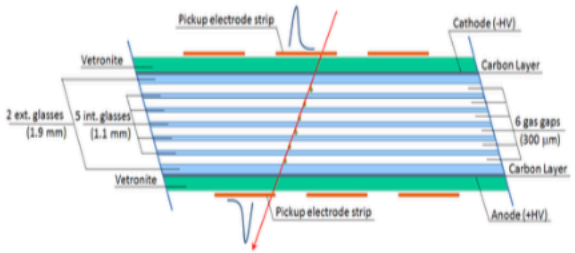
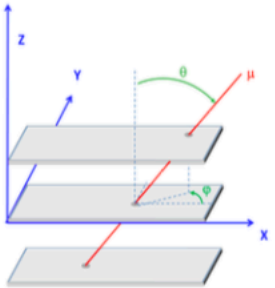
EEE Speed of Muon

Experimental Setup

The measure was performed by using the data collected, from 01/04/2019 to 05/04/2019, by a MRPC (*Multigap Resistive Plate Chamber*) telescope in use by EEE collaboration and placed in Vicenza (Italy)



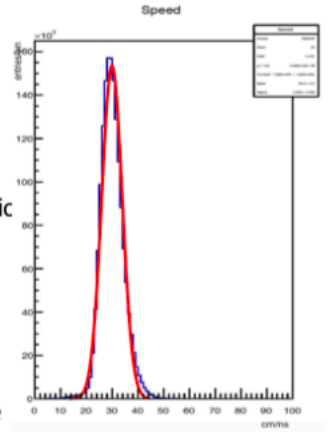
This kind of detector provides us with track length and time-of-flight of each event, as well as the angular coordinates (φ, ϑ) Identifying the trajectories direction.



Analysis

Our data analysis was performed by using the software ROOT. We took into account only events where the hit positions on each of the three chambers are well fitted with a straight line. For this purpose we did the cut of $\chi^2 < 5$. We also performed a cut on zenithal θ angle, considering only $0 \leq \theta \leq 40°$.

We built a histogram of ratio between tracks length and corresponding times-of-flight, exhibiting a symmetric shape that we fitted with a Gaussian line. In this way, the mean value of the best Gaussian fit can be taken as the measure of muon speed while its variance can be considered an estimate of the measurement uncertainty.



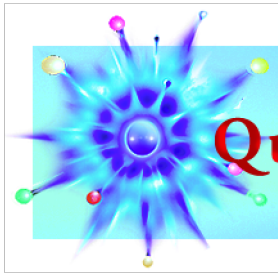
Results

The value we found for the muon speed is

$$v = 29,9\ cm/ns \quad \text{with} \quad \sigma = 4,0\ cm/ns$$

Very close, as expected, to the light speed

Liceo Scientifico "Leonardo da Vinci"



Summary of Speed Results

Thanks to all participants!

QuarkNet scintillator detectors: 2 ns timing resolution; no tracking; special runs

27.2 +-3.3 cm/ns

EEE tracking chambers: 0.28 ns timing resolution; fine tracking; normal data set

28.9 +- 0.8 cm/ns

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GPS back-to-1999 Error

US GPS system hardware failed on April 6, 2019; started reporting the date as either 1980 or 1999.

A 10-bit weekly data counter rolled over plunging all QuarkNet GPS receivers back to 1999!

Data could not be uploaded to QuarkNet e-Lab.

Time is still precise to 100ns, with a 19 year offset!

A firmware update was required to fix the date.

Some Fermi Neutrino Experiments also went offline.

We apologize to QuarkNet DAQ users around the world.

- follow instructions to download yourself or
- send us your GPS card and we'll download new firmware

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Muon Underground Shielding Experiment

Measure Muon Rates in the Fermilab MINOS Tunnel

Cosmic ray rate as a function of distance from the 4m diameter access shaft (105m underground)

Teachers and students from 6 high schools designed experiment in Fall 2018
Submitted proposal to Fermilab Dec. 2018
Built prototypes; measured rates versus angular acceptance
MUSE Approved in March

Wonderful support from Fermilab and Neutrino Division
Minor students couldn't access the tunnel but participated via live feeds
Collected data March – May 2019 changing position every weekend
5m-90m from shaft

3 detectors: 1 vertical stack on surface for normalization;
2nd identical stack in tunnel;
3rd detector in tunnel – non-vertical muons and background muons along the neutrino beamline.

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MUSE

High School Muon Underground Shielding Experiment

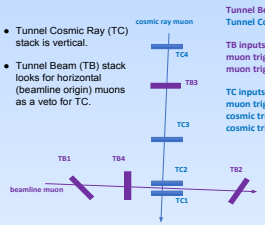
New Trier HS
Glenbrook North HS
Ida Crown HS
Downers Grove South HS
Rochelle Zell HS
Naperville Central HS
University of Illinois at Chicago
QuarkNet

Goals

- Measure the change in cosmic ray muon flux in the MINOS neutrino tunnel as we move downstream from the access shaft.
- Measure the change in flux as we descend to the tunnel in the elevator.
- Monitor three angular acceptances simultaneously.
- Add results from this measurement of vertical cosmic ray muons to the previous large angle measurements from MINOS

Setup

- Tunnel Cosmic Ray (TC) stack is vertical.
- Tunnel Beam (TB) stack looks for horizontal (beamline origin) muons as a veto for TC.



Tunnel Beam = TB
Tunnel Cosmic Ray = TC

TB inputs: 1,2,3,4
muon trig beam = 124
muon trig shaft = 13; 23

TC inputs: 1,2,3,4
muon trig large acceptance = 12
cosmic trig medium acceptance = 123
cosmic trig large acceptance = 124 or 1234

- Three Detectors:
  - One to monitor cosmic rays above ground as a control.
  - An identical detector (TC) to measure the rate underground.
  - A third detector (TB) to measure the muon background in the neutrino beam.
- The cosmic ray detectors simultaneously record data in wide (150 deg), large (21 deg), and small (6 deg) angular acceptance modes.

Surface Module

Tunnel Module

Acknowledgements

Thank you to Fermilab for allowing us to use their facilities through the approval of TSW 1548. We acknowledge the National Science Foundation for their fiduciary assistance in establishing and maintaining QuarkNet (Grant #1806631). We would like to extend additional thanks to administrators of the affiliated schools for their continued support of this project.

U.S. DEPARTMENT OF ENERGY | Office of Science | QuarkNet

UIC UNIVERSITY OF ILLINOIS AT CHICAGO Department of Physics
COLLEGE OF LIBERAL ARTS & SCIENCES

March 2019

Muon rates approximately 0.5% of rates on the surface

Studied versus horizontal distance from access shaft

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Summary

International Muon Week – great increase in participation due to our EEE colleagues.

GPS hardware disaster – GPS cards being sent to Fermi to be updated and returned.

MUSE – fun in the MINOS neutrino tunnel.

200 QuarkNet groups upload data (out of 350 detectors in US and similar number outside the USA)

Lots of opportunities for student research

ICRC2019 held in Madison, USA in July– QuarkNet will present four cosmic ray posters : storms across Kansas; Solar Eclipse; MUSE; Cosmic Ray rate variation across Chile