A Measurement of the Angular Distribution of Cosmic Rays using a Spark Chamber

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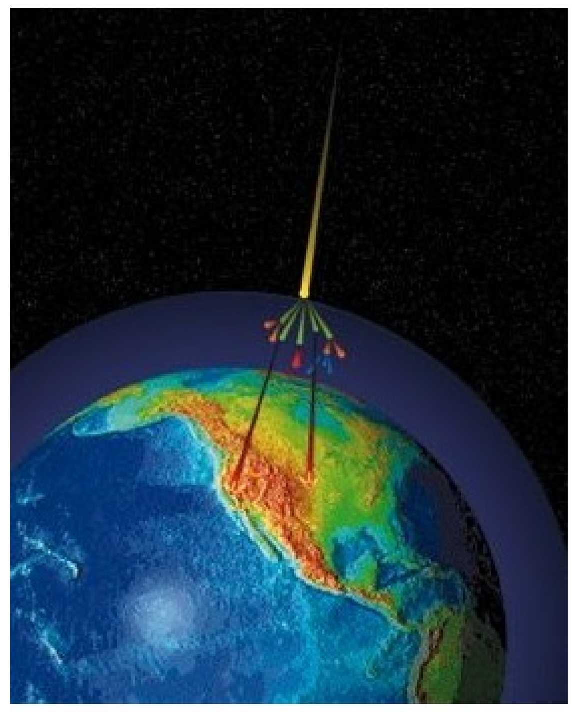
Introduction

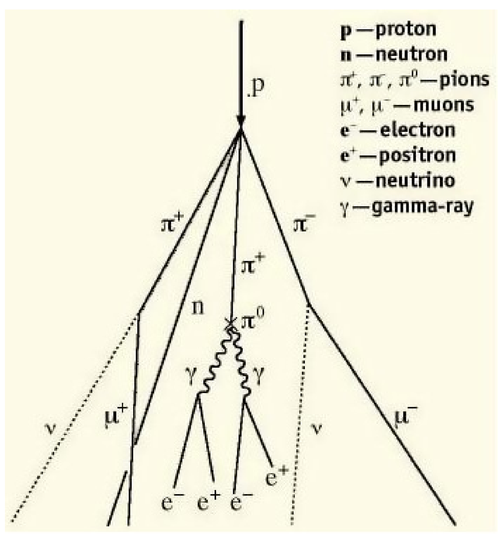
The angular distribution of cosmic muons arriving at the Earth's surface is measured using the spark chamber built at McGill under the supervision of Prof. Francois Corriveau. The trajectory of the particles can be observed as bright sparks passing through the detector and it is possible to reconstruct their paths by recording images of these sparks.


Particle showers in the upper atmosphere

New data acquisition and data analysis software have been written to record and measure the incident angles of cosmic muons as they pass through the detector. The results are compared to a currently accepted model for the angular distribution of cosmic rays whose distribution is of the form $I_0 \cos^2(\phi)$, where I_0 is the amplitude and ϕ is the incident angle (from the zenith) of the particles.

Cosmic Rays

Cosmic rays are charged energetic particles originating in outer space. There are two types of cosmic rays: primary and secondary.

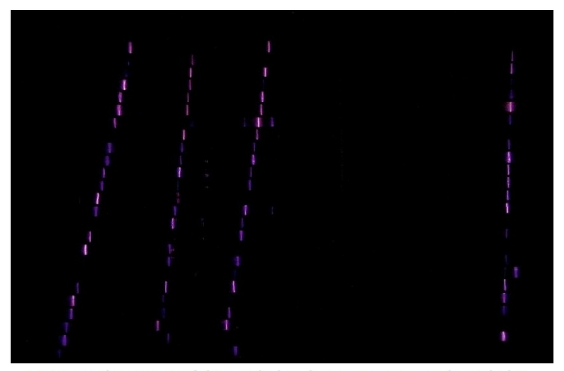


Particle showers in the upper atmosphere

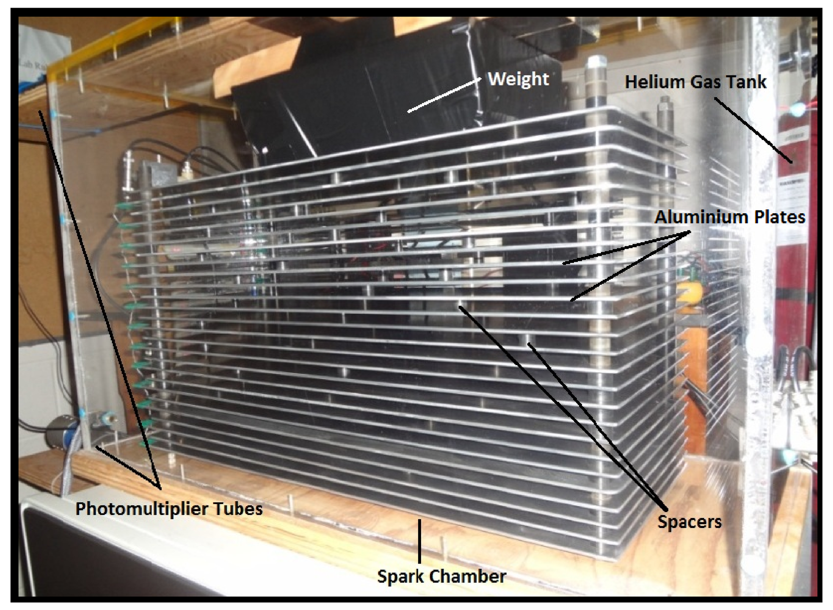
The primary cosmic rays are composed of 90% protons, while secondary cosmic rays are created when the primary rays enter the atmosphere and collide with air molecules, where particle showers occur. The protons scatter in the atmosphere and produce mostly pions (π^+, π^-, π^0), which then decay into muons and neutrinos. The muons produced have enough energy to reach the Earth's surface and even penetrate the surface in most cases.

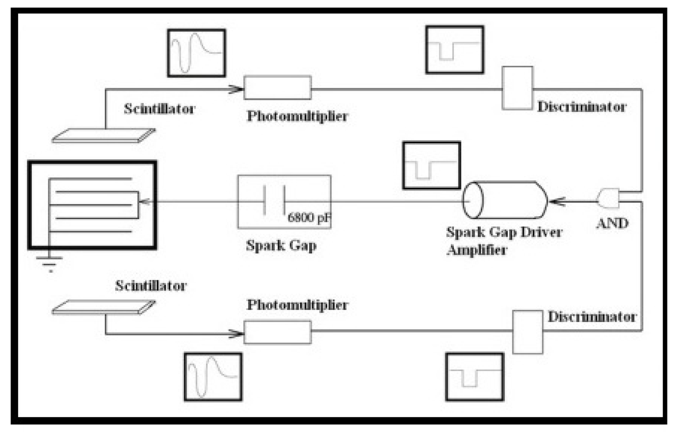
Data Acquisition

The image on the right shows a single long exposure of the Spark Chamber as charged muons pass through. Each track represents the path taken by one muon.


A 30 second exposure of the spark chamber as muons pass through the detector. Four separate particle trajectories may be seen in this image.

The Spark Chamber



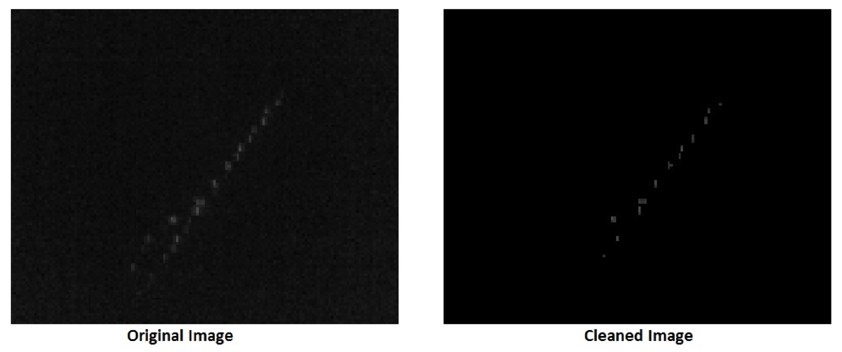


Schematic diagram of the Spark Chamber

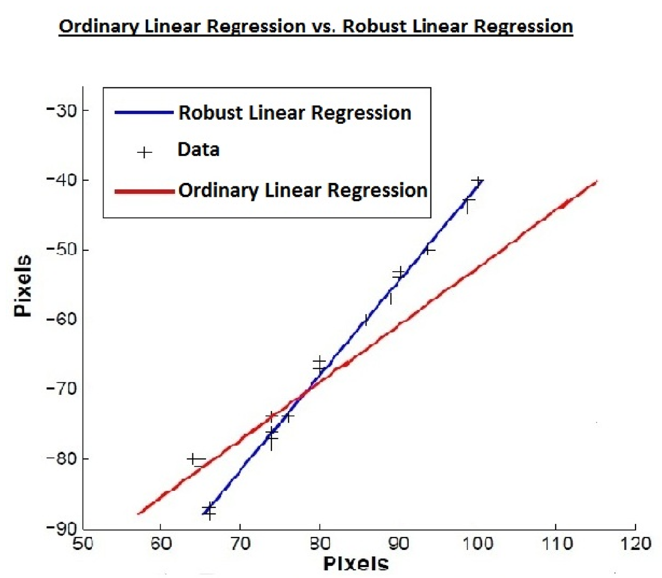
The Spark Chamber consists of alternating aluminium plates at 10000 Volts or ground, respectively, to generate sparks where the charged muon passed through. Scintillating plates are located above and below the chamber and trigger the high voltage when a charged particle passes through. The chamber itself is filled with helium gas; a gas that is easily ionized and relatively cheap.

Data Analysis

Instead of single long exposures, a video is recorded and its frames analyzed one by one using MATLAB. The frames containing an event are cleaned up, removing any background noise due to reflections off the back wall of the chamber and light leaking into the room.



The remaining bright points are fitted using a robust linear regression fit function. A typical fit is shown on the right and is compared to an ordinary linear regression fit function. It is clear that the second fails if an outlying spark is present, which occurs due to a buildup of charge along the plates and does not represent the path taken by the particle.

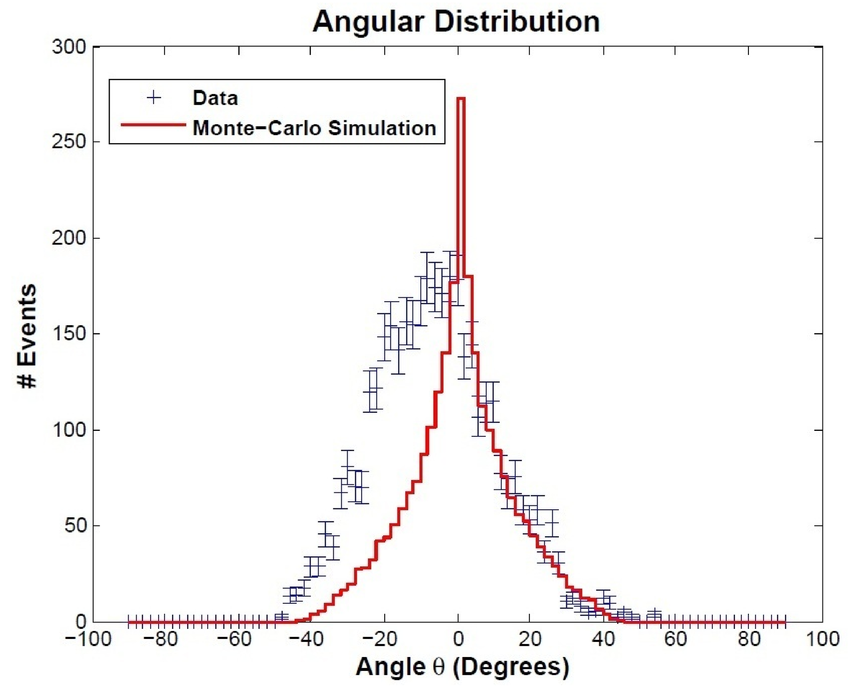


A comparison between robust linear regression (blue) and ordinary linear regression (red). The second fails when an outlying spark is present

Results

The incident angles of cosmic muons passing through the chamber are measured and are binned in intervals of 2°, after adjusting for the acceptance of the detector.

The data is represented as black crosses and is compared to a Monte-Carlo simulation (red). The angle θ is not the true angle of incidence (ϕ); it is instead this angle projected onto a 2D surface, a result of recording with one camera only. The Monte-Carlo simulation represents the $\cos^2\phi$ distribution after this projection.



The data follows the Monte-Carlo simulation near the positive angles, but overshoots it near the negative anlges: closer to the photomultiplier end of the trigger scintillators. This suggests that the efficiency of the detector is not uniform along its length, meaning that more particles are detected towards the left end of the detector than the right.

Conclusion

The angular distribution of cosmic muons was measured and compared to a Monte-Carlo simulation based on currently accepted models. Although the data does not follow the Monte-Carlo simulation perfectly, results suggest that the efficiency of the detector is not uniform along its length. The next step before conducting any more experiments with the spark chamber should be to test the efficiency of the scintillators at every location along their length.

Even so, the spark chamber proved itself an excellent teaching tool for several techniques in high-energy physics and an invaluable demonstrator for observing and monitoring elementary particles in the lab.

Acknowledgments

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