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Using Experimental Instrument and Equipment Cosmic Watch Detects Muon

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Abstract. We used the cost-effective detector Cosmic Watch to replicate the Rossi curve for data at a single thickness, and then conducted data analysis. Our 6 cosmic watches are arranged in pairs vertically and stacked one on top of the other. The absorbers are air, 0.8 cm thick iron, and 5 cm thick lead. We use Python for plotting and created graphs of the timestamp of all detector files against the Number of events, as well as the Number of events against time. Subsequently, the rate of each (though some data files were damaged) detector is shown with the calculated error ranges on another graph. Finally, we visualize the graph of time difference against event time for the two detectors stacked vertically and diagonally.

Keywords: cosmic ray, cosmic watch, Rossi curve, muon

1. Introduction

Rossi's transition curve displays the coincidence rate of stacked counters as a function of absorber thickness, revealing a rise–peak–fall pattern that separates the soft electromagnetic component from the hard, penetrating muon component [1].

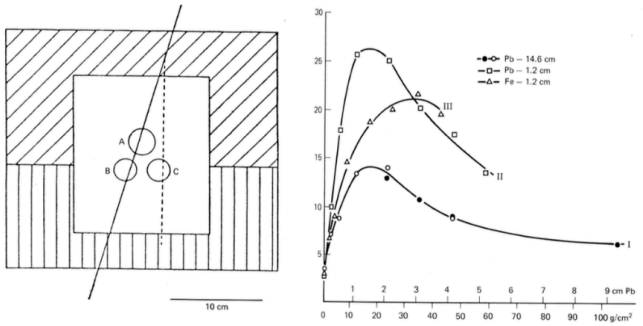


Figure 1. Rossi's transition curve [1]

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In extensive air showers, a high-energy primary (usually a proton or nucleus) collides with an atmospheric nucleus and initiates a cascade. Neutral pions feed the electromagnetic branch ($\gamma \rightarrow e^{+}e^{-}$ via pair production and bremsstrahlung), while charged pions yield μ^{+}/μ^{-} and ν. Muons are spin 1/2 leptons, mass $\approx 207\,m_e \approx m_p/9$ with a lifetime of $2.2\,\mu s$[2]. Because the differential intensity of cosmic rays falls as a power law $J(E) \propto E^{-\gamma}$ with $\gamma \approx 2.7$, direct high-precision measurements become impractical by about 10^{14} eV for balloon or space-borne detectors. Instead, one exploits the abundant secondaries in the atmosphere: transverse momentum at production and multiple scattering spread particles laterally so that many arrive nearly simultaneously over large areas—an extensive air shower (EAS). At 10^{15}eV a typical shower contains 10^{6} particles over $10^{4}\,m^{2}$, and by 10^{20}eV as many as 10^{10}-10^{11} particles can cover $10\,km^{2}$[3]. Cosmic rays form a non-thermal population spanning tens of MeV to nearly 1 ZeV; above 1 GeV the integral intensity is $10^{4}\,m^{-2}\,s^{-1}\,sr^{-1}$, consistent with this power-law behavior [4]. In cosmic watch , When a charged particle traverses a scintillator, part of its energy is converted into optical photons. These photons are read out by a silicon photomultiplier (SiPM) coupled to the scintillator. Because even a single photon can trigger a detectable avalanche, the SiPM output is amplified and shaped so an Arduino Nano can determine both the photon count and the arrival time. Each photon produces a voltage pulse at the SiPM output. A peak-detector stage lengthens this pulse, allowing the 16 MHz Arduino to take multiple samples and reconstruct the original SiPM pulse height from them [5].

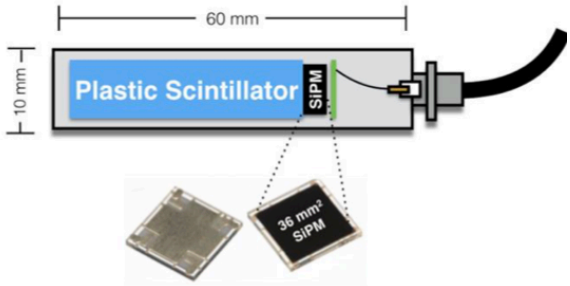


Figure 2. mTOM module [6]

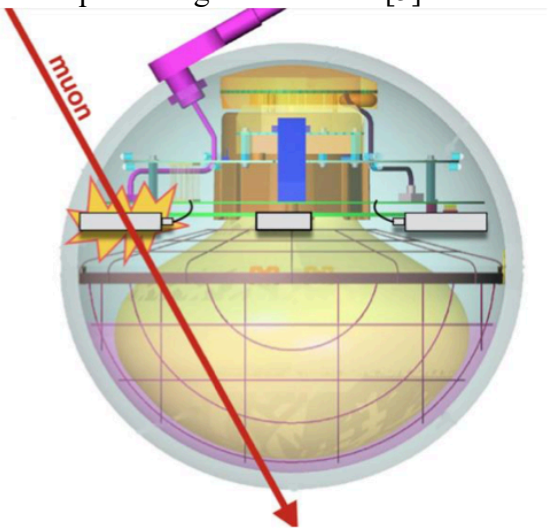


Figure 3. Muon tagging in IceCube DOM [6]

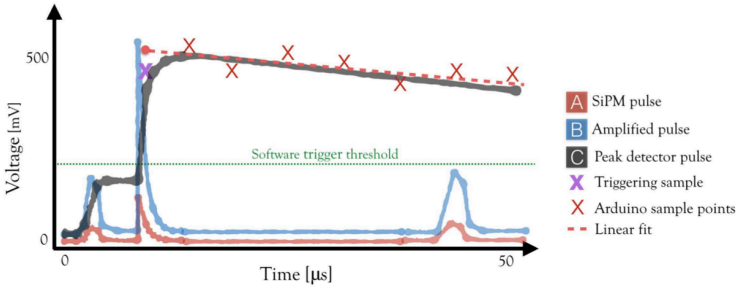


Figure 4. Pulse waveforms vs time [6]

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2. Analysis

We first analyze the number of timestamps versus the event count for coincidence = 1 and coincidence = 0. The scatter plot is approximately a straight line, indicating that muon events occur roughly uniformly in time. Small fluctuations around the line are attributable to noise or instrumental effects.

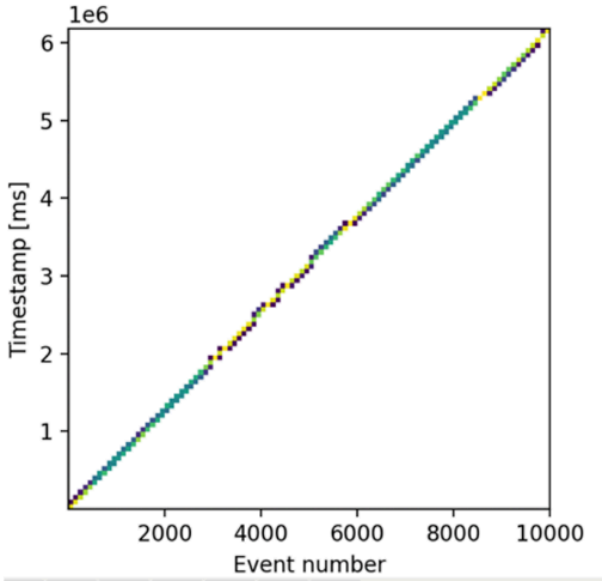


Figure 5. Timestamo vs event number

Next, a one-dimensional histogram of event count versus time shows average of about 13 events per bin, with variations around this mean value.

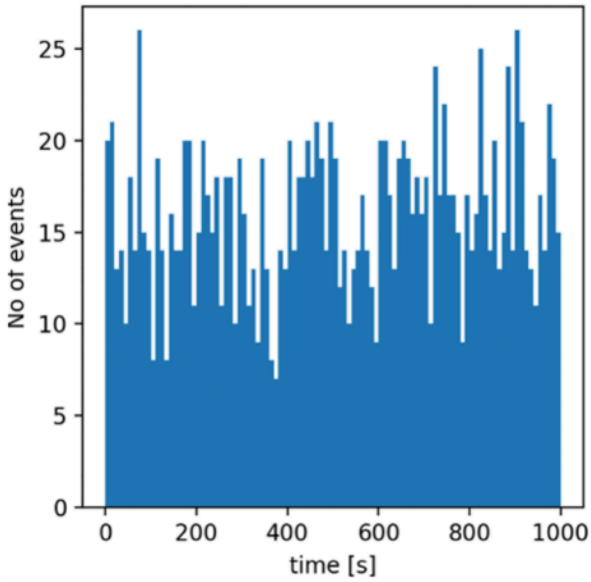


Figure 6. No of events vs time

We then examine pressure as a function of time to identify runs taken simultaneously. If two pressure–time curves share the same trend, the corresponding measurements are concurrent. For

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example, the pressure profiles of B45/2 and T02/2 closely match, confirming the data are recorded in the same period and can be compared directly in later analysis.

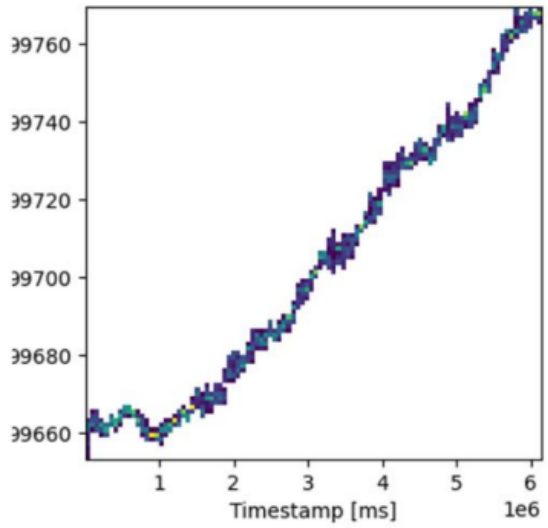


Figure 7. Pressure vs timestamp B45/2

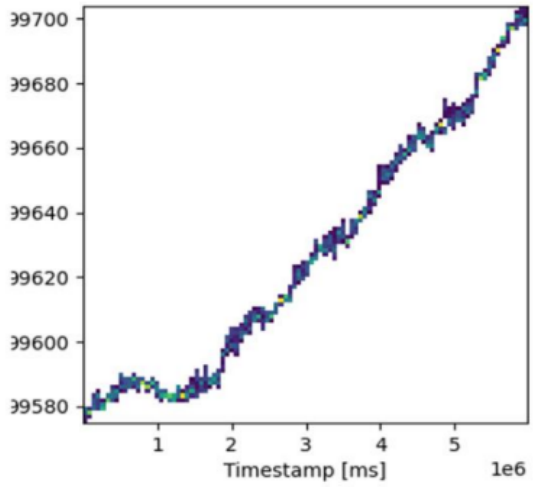


Figure 8. Pressure vs timestamp T02/2

Because T02 sits vertically above B02 and the pair is connected, coincidence = 1 marks muons traversing both detectors. Although the two detectors begin running at nearly the same time, their internal clocks do not tick at identical rates. Consequently, timestamps of coincident events are misaligned and the mismatch grows with time due to clock drift.

The distribution of time differences (T02/2 – B02/2) over all events exhibits a strong peak between about 900 and 500 ms, revealing a non-zero initial offset plus relative clock drift.

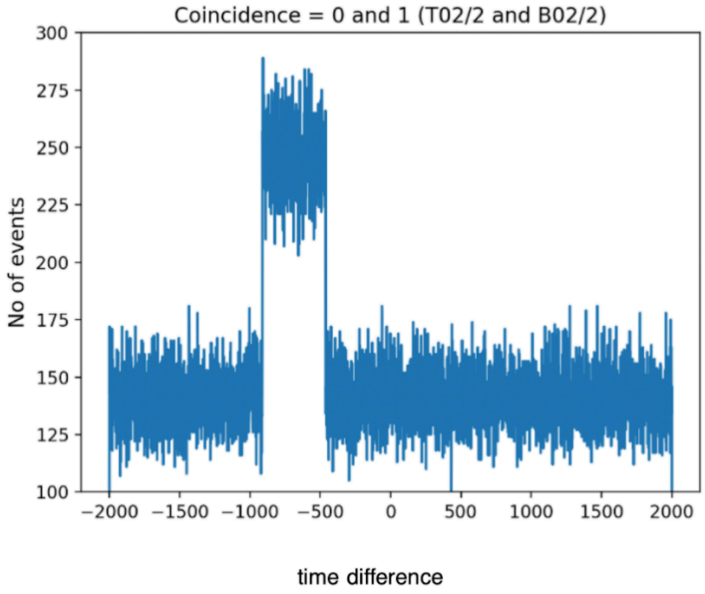


Figure 9. No of events vs time difference

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A 2-D plot of time difference versus event time further shows a clear linear trend: at t = 0 the offset is roughly 1000 ms, and the positive slope indicates one clock runs faster.

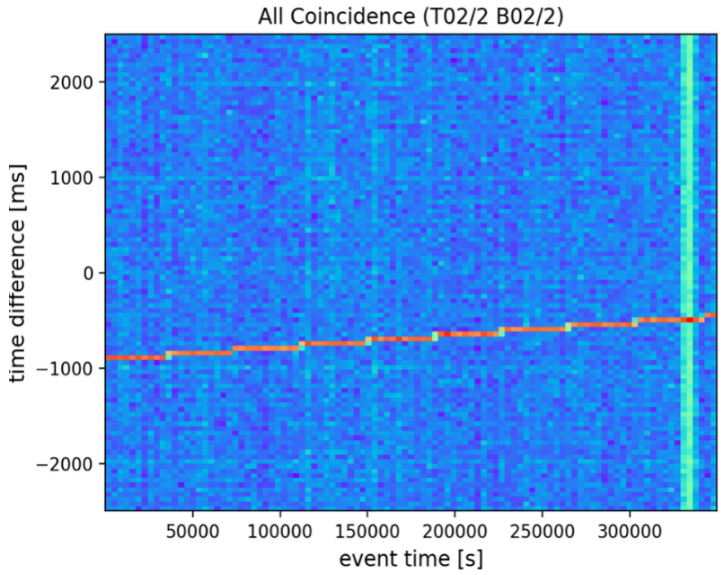


Figure 10. Time difference vs event time before correction

This systematic timing discrepancy can be removed by applying a linear correction to one detector's timestamps until the distribution is centered at zero time difference with no drift.

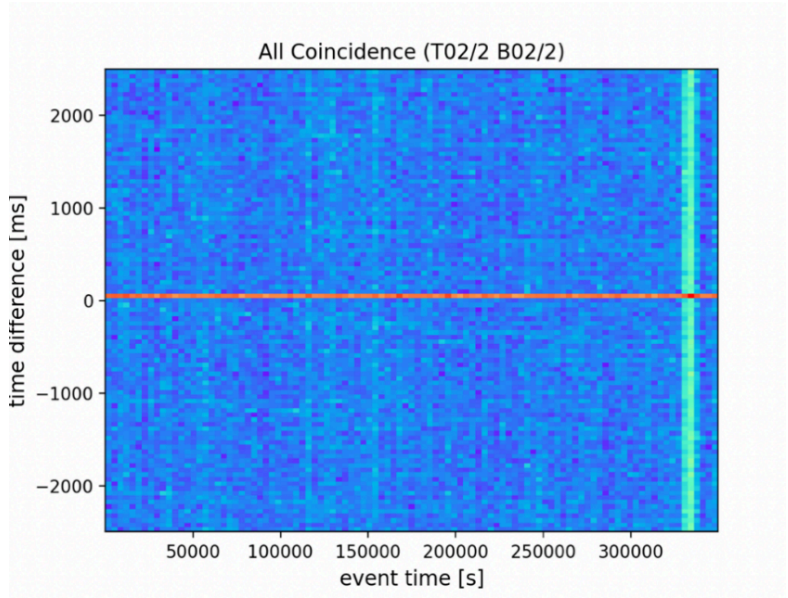


Figure 11. Time difference vs event time after correction

In contrast, analyzing T02/2 vs B02/2 under coincidence = 0 shows no linear structure in the 2-D time-difference plot, confirming that the trend above is specific to coincidence = 1 events.

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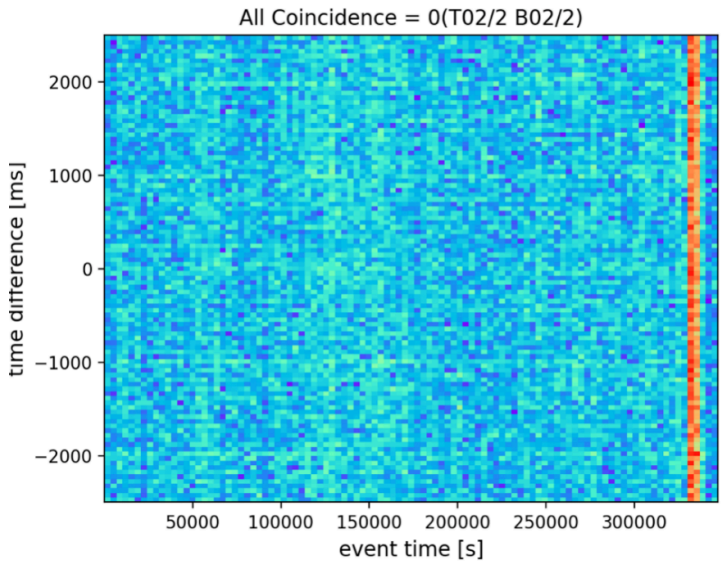


Figure 12. Time difference vs event time all coincidence=0

We also study T02 and B45, which are neither vertically nor horizontally aligned. In this configuration, a single muon traversing both detectors is recorded as coincidence = 0, so only such events are considered here.

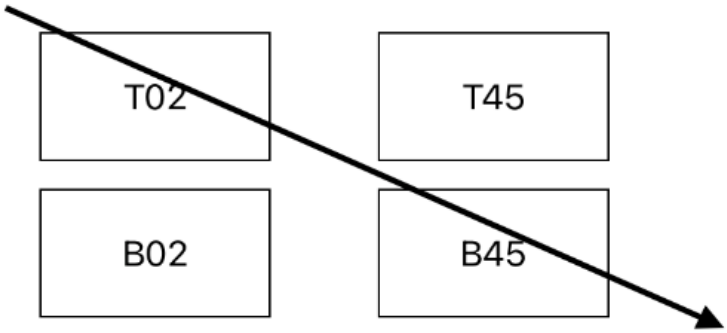


Figure 13. Cosmic Watch operation schematic diagram

For T02/2 vs B45/2 under coincidence = 0, the 2-D plot of time difference versus event time shows a distinct tilted line corresponding to double-detector muon events.

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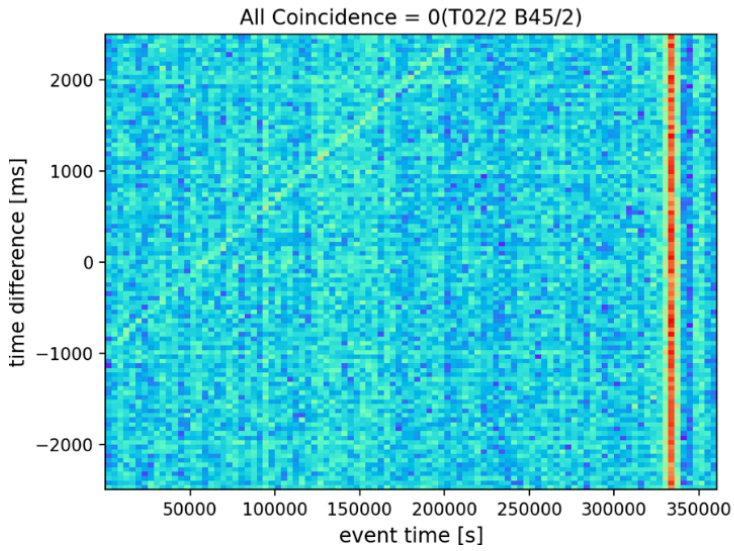


Figure 14. Time difference vs event time T02/2 B45/2 before correction

The non-horizontal orientation and non-zero intercept again reflect unsynchronized clocks and differing drift rates. To align timelines, we apply a linear timestamp correction to one detector so that the line becomes horizontal and centered at zero time difference.

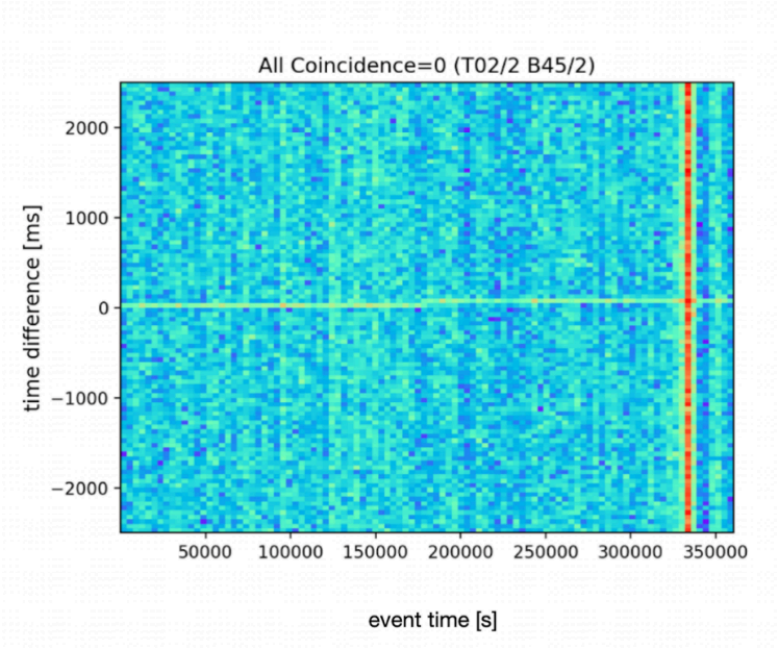


Figure 15. Time difference vs event time T02/2 B45/2 before correction

3. Conclusion

The event rate is stable (≈13 per time bin), and consistent pressure–time traces across channels indicate concurrent data taking enabling direct comparison. Time-difference analysis for both the vertically stacked and non-aligned pairs show an initial ≈−1 s offset with linear drift for true double-detector events. A simple linear correction to one detector's timestamps removes the slope and

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centers Δt near zero, achieving clock alignment. With the timelines corrected, the datasets are suitable for unbiased coincidence analysis and downstream physics, including cross-detector rate comparisons and studies of barometric effects on the muon flux.

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