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eMuon Decay as a Robust Long-Term Calibration Method for Water Cherenkov Detectors

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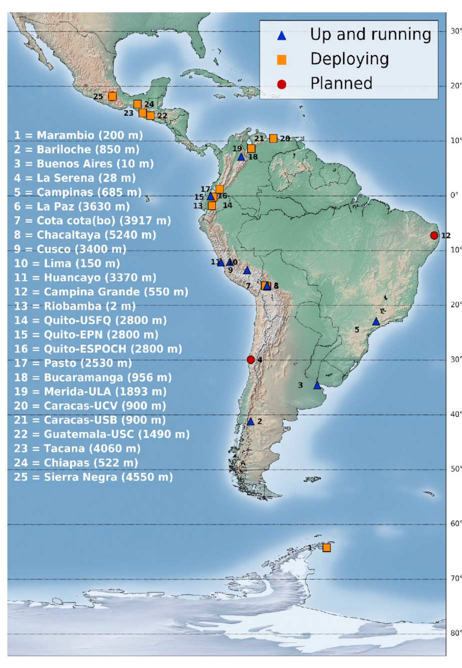
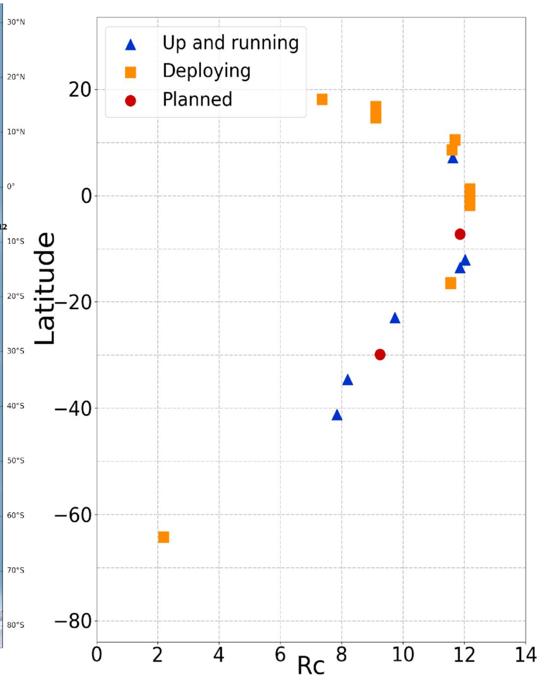
1 LAGO WCD Network



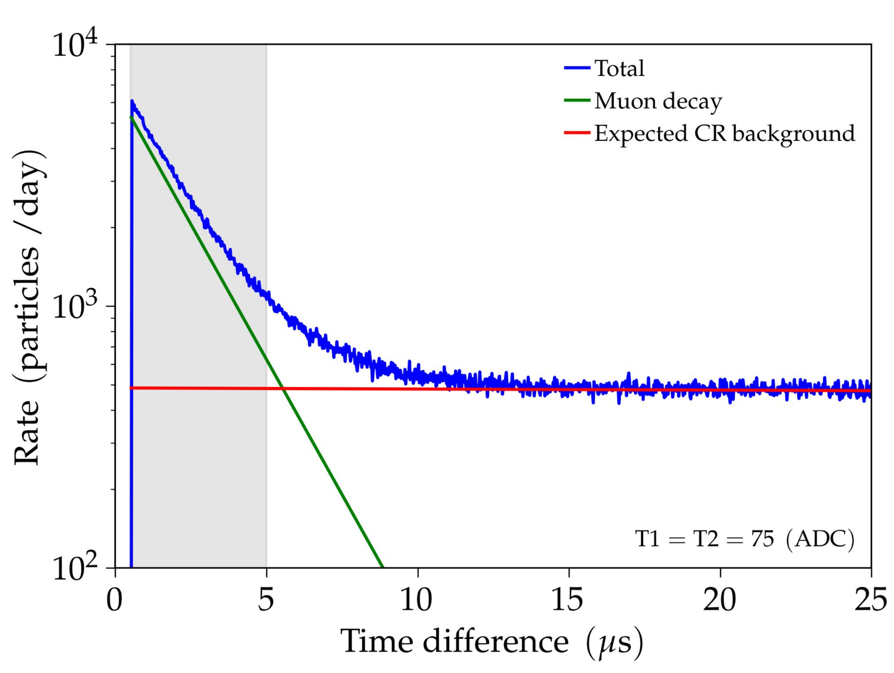


The Latin American Giant Observatory (LAGO) is a **network of Water Cherenkov Detectors (WCD)** in Latin America, with a large variation in altitudes, and rigidity cutoffs and **detector geometries**.

Two WCDs of the LAGO network: one in Bariloche, Ar (Nahuelito, left) the other in Arequipa, Peru (Characatito, center). The Cherenkov light produced in purified water by extensive air showers' (EAS) secondary particles entering the detector is measured by a 9" photomultiplier tube (PMT) centered at the top of the detector (right).

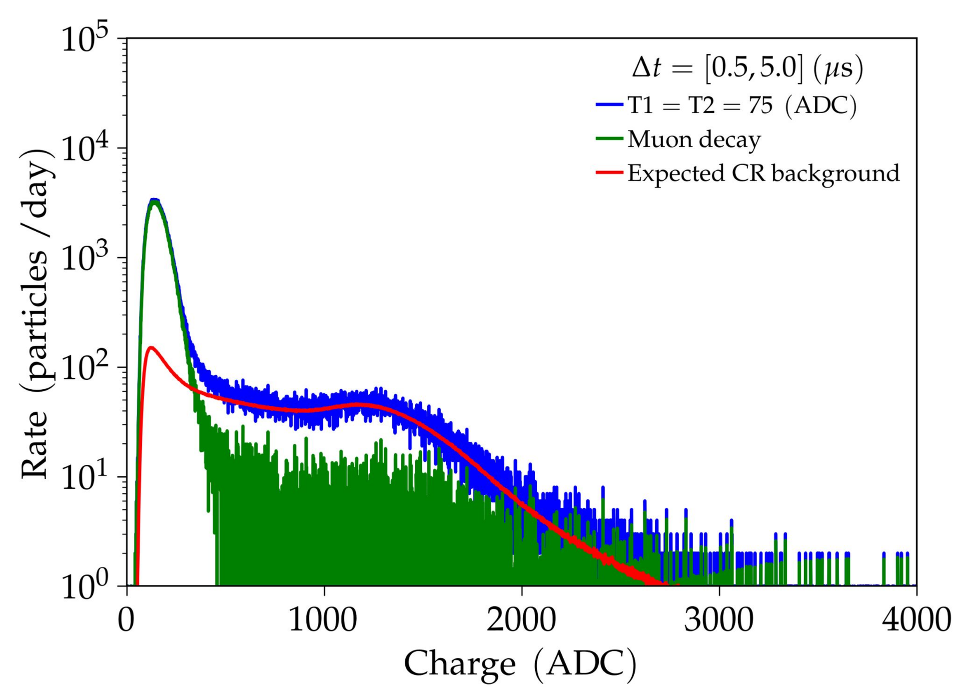
2. Michel and Muon espectrum

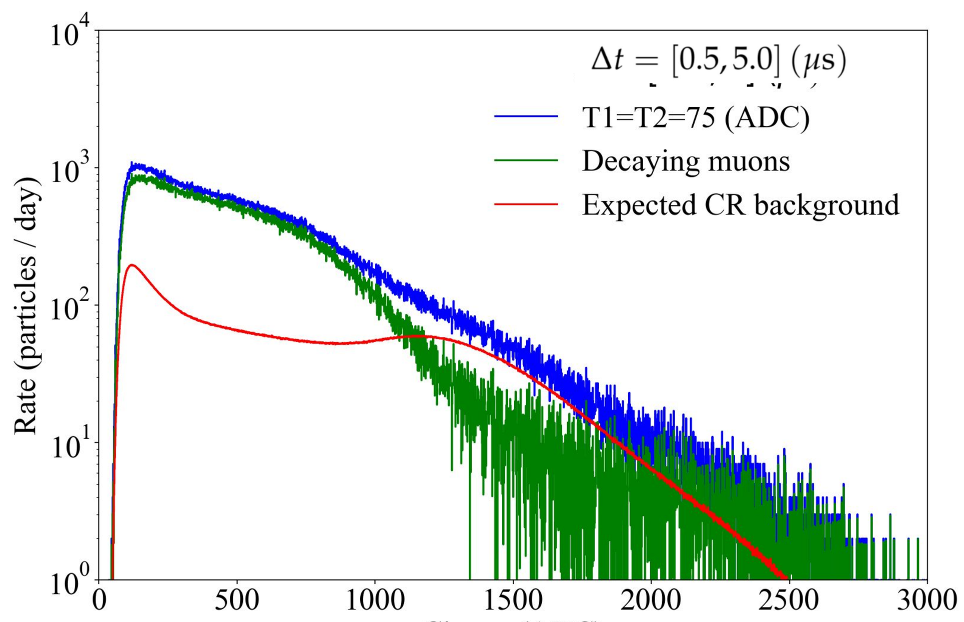
WCDs produce a characteristic pulse-like signal when an EAS' secondary particle (SP) crosses the detector volume. Atmospheric muons can decay inside the WCD while traversing or stopping on it. These muons decay in water with a mean lifetime τ_μ<~2.2 µs producing electrons (Michel electrons) with enough energy to generate their own detectable pulses. We are able to estimate the spectra of Michel electrons and their parent, decaying muons as described below for the Nahuelito WCD:



*i) we adjust the **time difference histogram** with two exponential functions, one corresponding to the **cosmic ray background** and the other to the **muon decay**. From this, we estimate the SP flux on the **0.5 - 5 µs band.***

*ii) the **charge spectrum of Michel electrons** is estimated by selecting the **second pulse of two consecutive pulses with a time difference between 0.5 and 5 µs,** and subtracting from the **expected charge histogram of the SP flux.***

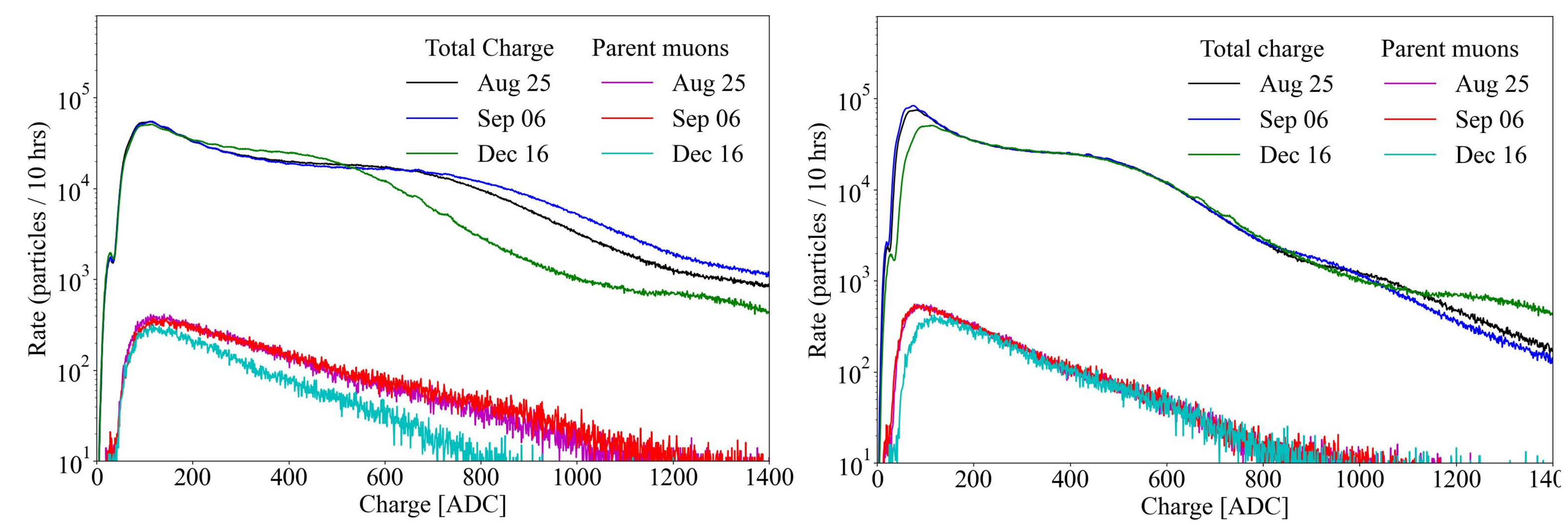




*iii) the **charge spectrum of parent muons** is then estimated by selecting the **first pulse of both consecutive pulses with a time difference between 0.5 and 5 µs** subtracting from the **expected charge histogram the SP flux.***

3. Calibration method

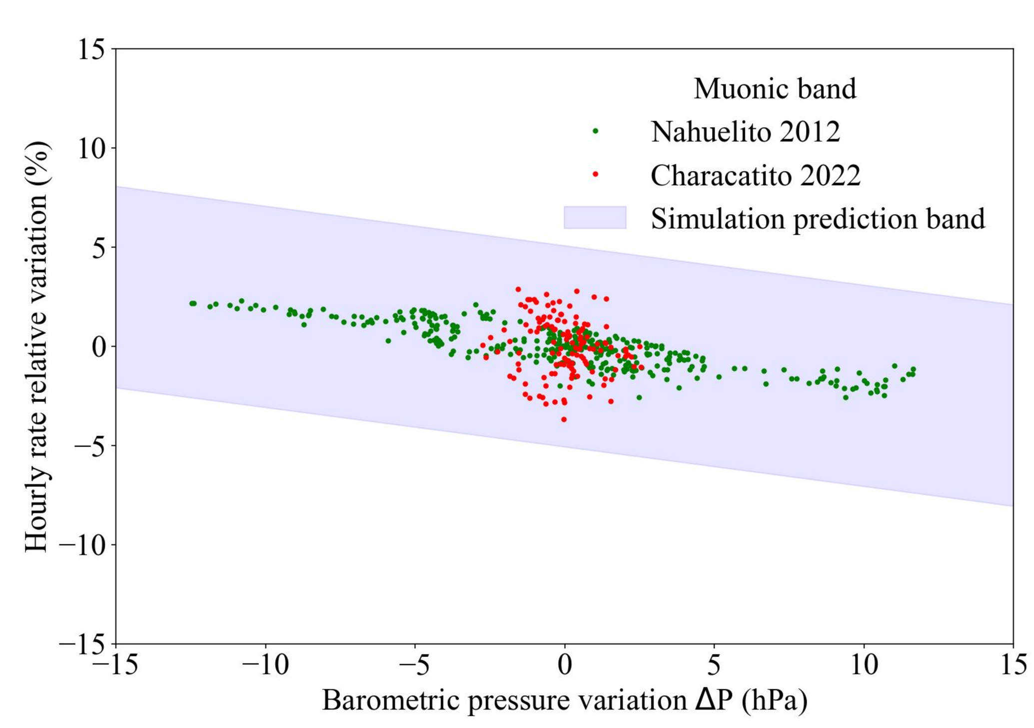
Over long monitoring periods (e.g., months to years), we observed significant compression in the charge spectra of some WCDs in the LAGO network. This is attributed to water degradation altering the detector response and calibration stability. To address this, we developed a novel calibration method based on the charge spectra of decaying muons in a daily basis, which is independent of altitude and atmospheric variations, using them as **independent and robust calibration constant**.

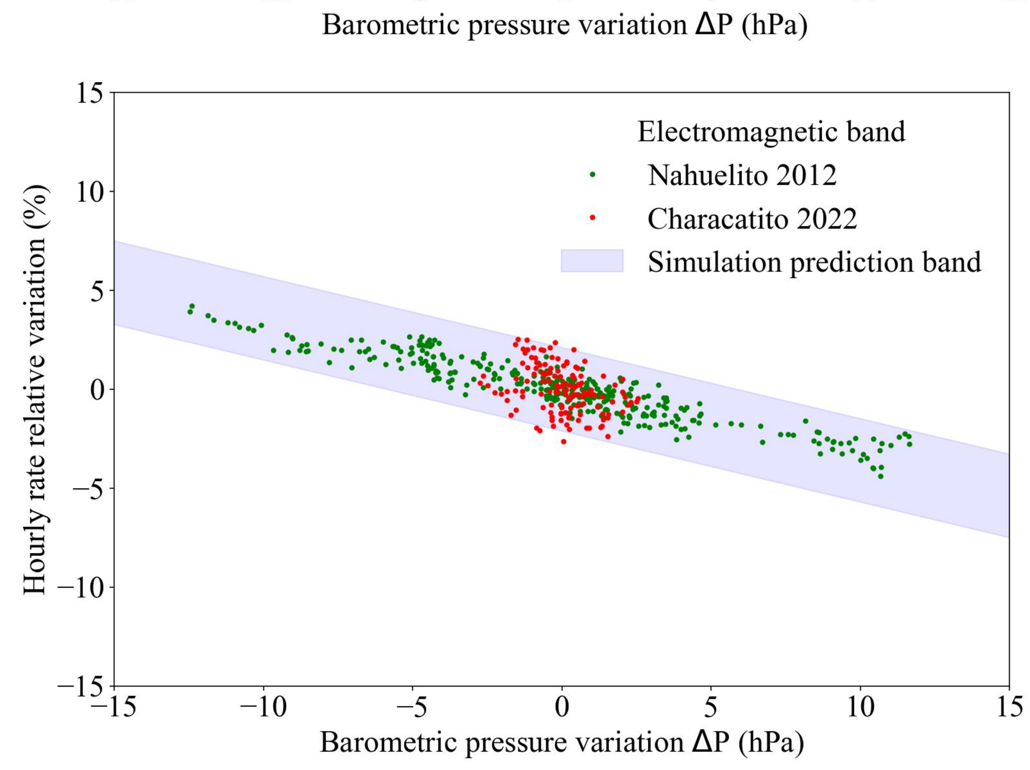


Charge histograms of the Chacaratito detector before (left) and after (right) applying the muon decay calibration procedure.

4. Long term test

We performed simulations of the response of our WCD to atmospheric muons using the ARTI framework, from which the expected flux of secondary particles at the detector level was obtained. ARTI accounts for geomagnetic effects, site altitude, and local atmospheric conditions to provide an accurate estimation of the SP flux at ground level, and a detailed Geant4 model of the WCD response considering the different geometries, water quality and detector characteristics.





*Using our simulated models, we derived a 95% confidence level (CL) **"prediction band"** for the well-established anticorrelation between secondary particle (SP) flux and barometric pressure. This analysis was performed separately for two components—muons and the electromagnetic component (e±, γ)—within the range of maximum flux sensitivity for both **Characatito** and **Nahuelito**.*

5. Conclusions

We have developed a novel methodology for the long-term calibration of LAGO Water Cherenkov Detectors, based on the precise determination of muon decay spectra. This approach is currently being replicated across multiple LAGO sites, including those at high altitudes. Furthermore, it can be integrated at the data acquisition (DAQ) level through the continuous monitoring of muon decay candidate events, thereby enabling robust and autonomous calibration over extended time scales.