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On the clustering methods of large muon events on the LVD detector

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Introduction

Large Volume Detector

Figure: LVD @ INFN Gran Sasso National Laboratory

Underground neutrino observatory mainly designed to study neutrinos from core-collapse supernovae

LVD

3 towers by $8 \times 5 \times 7 = 840$ counters
Main neutrino reaction:

$$\bar{\nu}_e + p \rightarrow e^+ + n \tag{1}$$

LVD can act as a beam monitor, detecting the interaction of neutrinos inside the detector and the muons generated by the ν_μ interaction in the rock upstream detector.

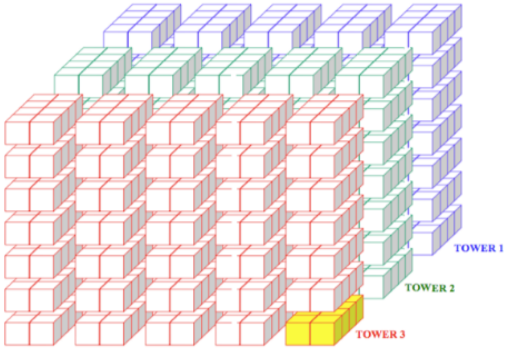


Figure: LVD counters arrangement scheme

Large muon event registration

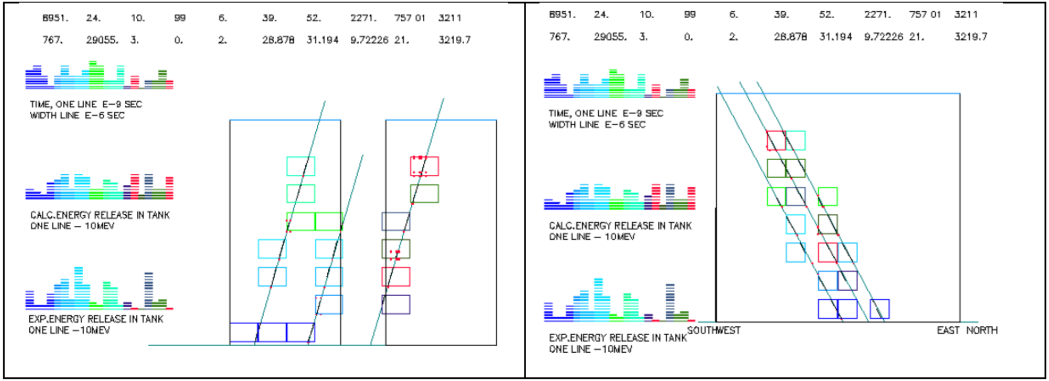


Figure: Multiple muon registration

Problem

Problem Statement

1. Neutrino bursts identification idea based on clusters of active events detecting
2. The task of clustering events in a partially ordered time series of detector counter readings
3. Clipping the size of events leads to
   - loss of large series detection
   - systematic error accumulation in the spectral distributions of observations

Previously. Fixed window approach

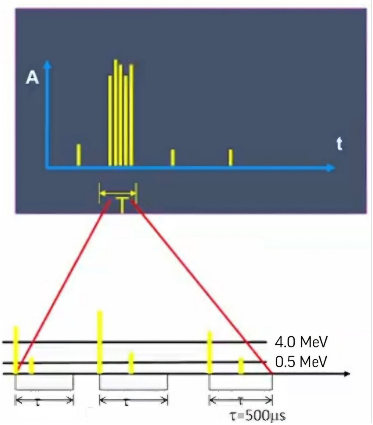


Figure: fixed window detection

Window opens at High energy threshold and listening everything for fixed time τ.

Methods

Preliminaries

Consider discrete-continuous impulse system where:

- the sequence number corresponds to the discrete internal time of the system
- the timestamp corresponds to the continuous "spatial" variable

Preliminaries. General log of all pules of all counters

High density of pulses inside the event

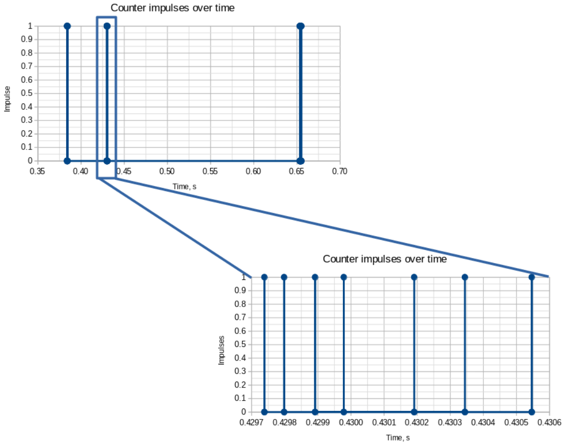


Figure: time series pulse log

Preliminaries

In order to separate events recorded in a single storage asynchronously, it is necessary to arrange them by a temporary variable

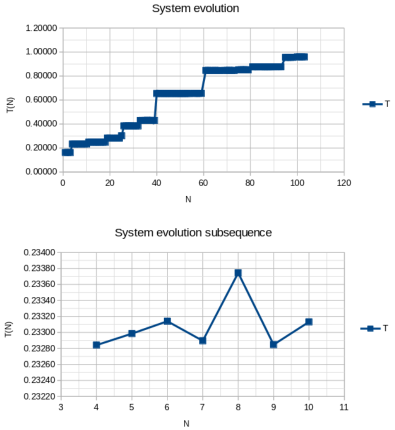


Figure: time series evolution

Preliminaries. Sorting epoch

1. Fill buffer
2. Sort it
3. Flush buffer until pivot
4. Move values after pivot instead of flushed elements

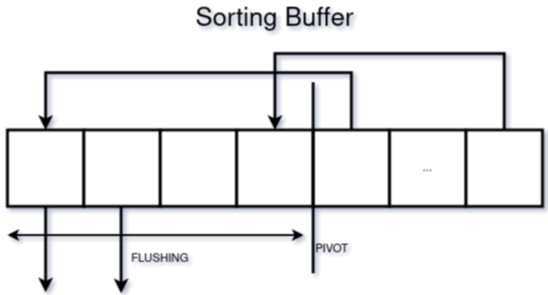


Figure: time series evolution

Preliminaries. After reordering

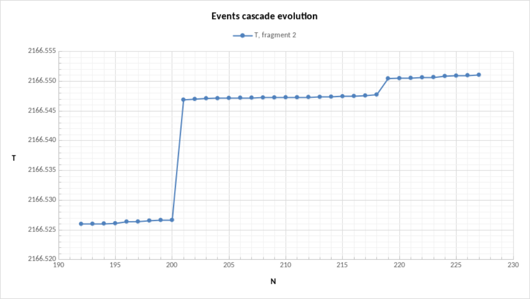


Figure: Events cascade evolution fragment

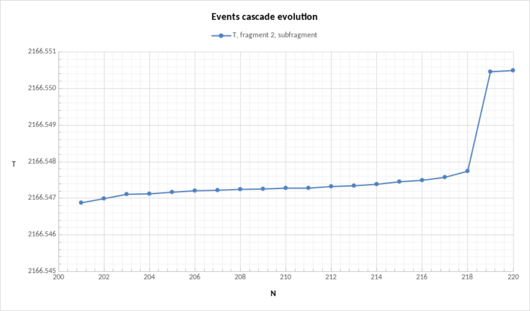


Figure: Events cascade evolution, its sub-fragment

Hypotheses 1. Uniform time evolution

The evolution of a time series system corresponds to an pulse system $T(N)$. Let us assume that temporal variable increases uniformly within an event cluster:

$$T(N+\Delta N) = T(N) + \Delta T = T(N) + k\Delta N \quad (2)$$

Thus, we require an invariant of the slope value' for cluster C_k:

$$k = T(N+1) - T(N)\ \forall N, N+1 \in C_k \quad (3)$$

Hypotheses 2. Non-increase variance

Assuming a normal error distribution, it can be assumed that the "next" temporal element, which strongly changes the variance of all calculated slopes of the event, does not fit to it.
For $C_k = N_{k_0}, ..., N_{k_i}$

$$\sigma_i^2 = VarX(N_{k_0} : N_{k_i}), \sigma_{i+1}^2 = VarX(N_{k_0} : N_{k_i}) \cup \{k_{i+1}\}, \quad (4)$$

$$(i+1) \notin C_k \Leftrightarrow \sigma_{i+1}^2 >> \sigma_i^2 \quad (5)$$

Spliiters

Let each of the online observers of the time series have a $CRIT$ value, the overcoming of which indicates the fulfillment of the hypothesis condition

1. $$k_{i+1} > k_{CRIT}$$
2. $$\frac{\left|k_{i+1} - \bar{k}\right|}{\bar{k}} > \varepsilon_{CRIT}$$
3. $$\sigma^2_{k+1} - \sigma^2_k > \Delta Var_{CRIT}$$
4. $$\frac{\left|\sigma^2_{i+1} - \sigma^2_k\right|}{\sigma_k} > \varepsilon Var_{CRIT}$$

Welford's statistics

Storing all cluster values consume memory. Calculating "Online": Regular

$$\bar{x}_n = \frac{(n-1)\,\bar{x}_{n-1} + x_n}{n} = \bar{x}_{n-1} + \frac{x_n - \bar{x}_{n-1}}{n}$$

$$\sigma_n^2 = \frac{(n-1)\,\sigma_{n-1}^2 + (x_n - \bar{x}_{n-1})(x_n - \bar{x}_n)}{n} = \sigma_{n-1}^2 + \frac{(x_n - \bar{x}_{n-1})(x_n - \bar{x}_n) - \sigma_{n-1}^2}{n}$$

Subtracting a small number from a large number $\rightarrow$ float point arithmetic instability

Welford's statistics

Storing all cluster values consume memory. Calculating "Online": Welford

$$\bar{x}_n = \frac{(n-1)\,\bar{x}_{n-1} + x_n}{n} = \bar{x}_{n-1} + \frac{x_n - \bar{x}_{n-1}}{n}$$

$$M_{2,n} = M_{2,n-1} + (x_n - \bar{x}_{n-1})(x_n - \bar{x}_n)$$
$$\sigma_n^2 = \frac{M_{2,n}}{n}$$

Voting ensemble

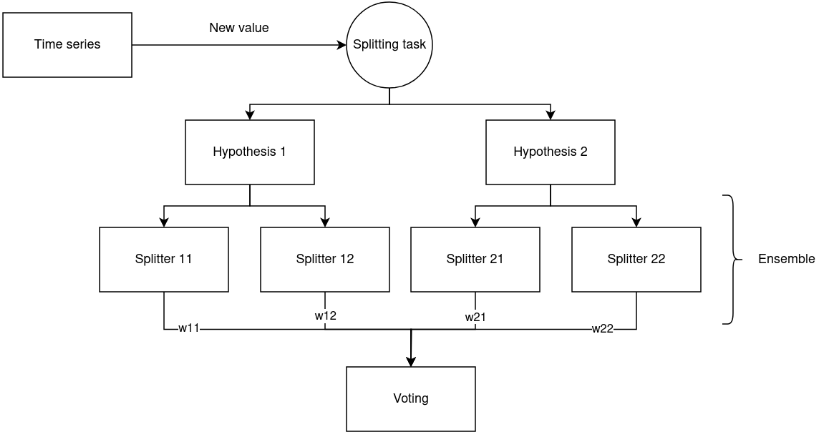


Figure: scheme of voting ensemble

Analysis

Measurements density

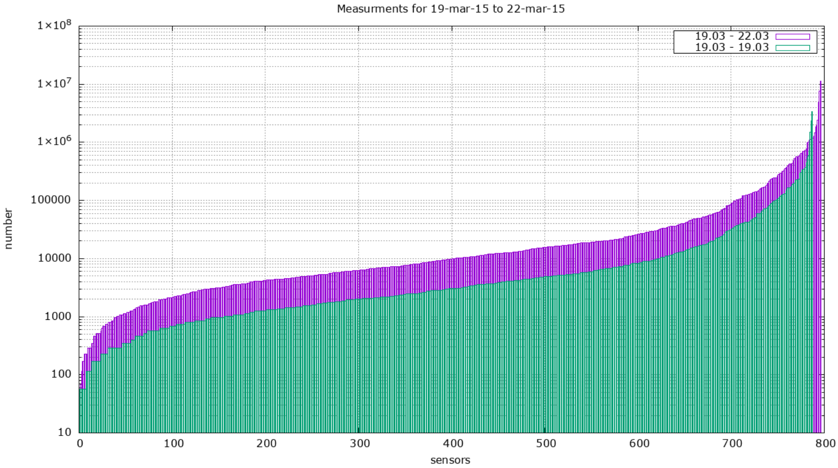


Figure: Counters pulse density

T(N) Evolution

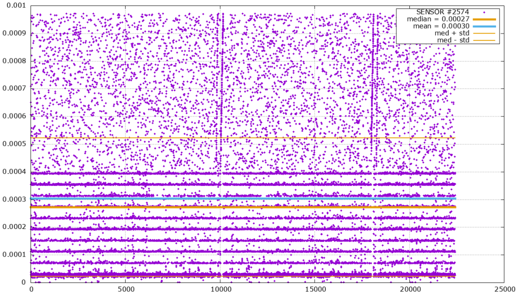


Figure: Counter evolution

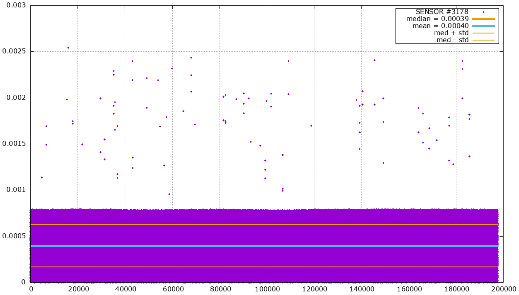
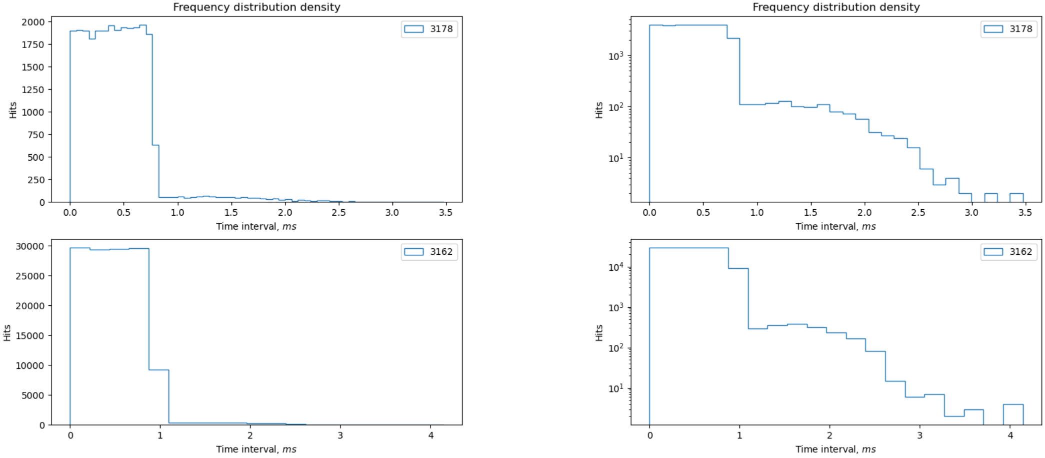
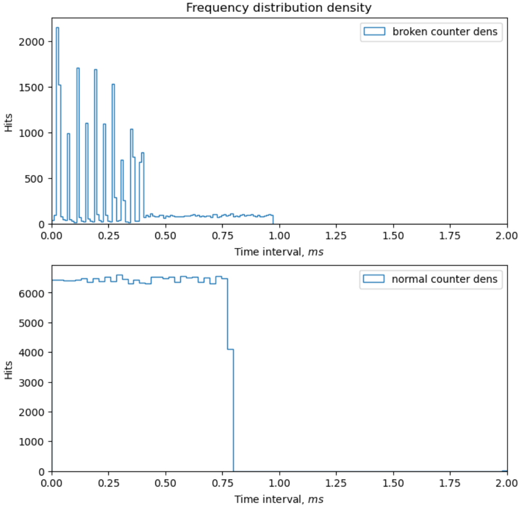


Figure: Counter evolution

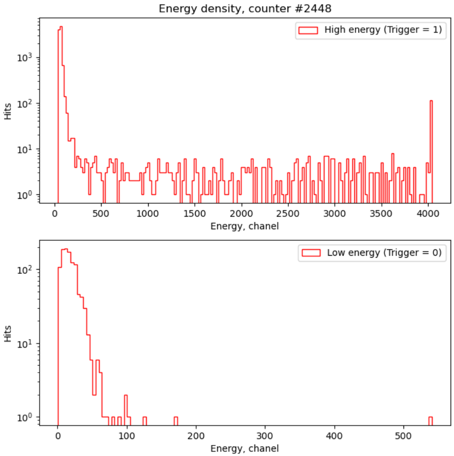
Distribution of the counting rate

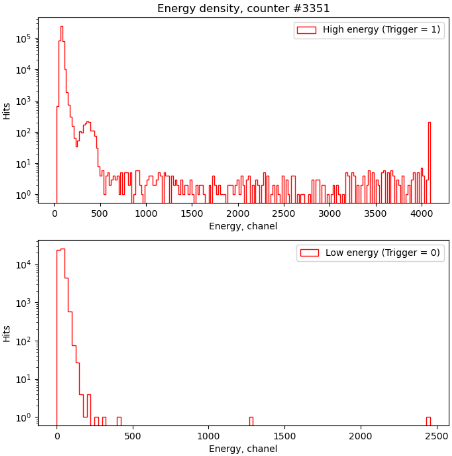


Normal and probably broken counter comparison



Distribution of the energy





Conclusion

Conclusion

The considered approach can be applied to the problem of clustering muon large events on the LVD

References I

- *Agafonova, N.Y., Ryazhskaya, O.G. & LVD Collaboration.* LVD—Multipurpose Russian–Italian Detector. Phys. Atom. Nuclei 85, 79–85 (2022)
- *Agafonova, N., Aglietta, M., Antonioli, P., Bari, G., Bonardi, A., Boyarkin, V., Bruno, G., Fulgione, W., Galeotti, P., & Garbini, M.* On-line recognition of supernova neutrino bursts in the LVD. Astroparticle Physics, 28(6), 516–522. (2008)
- *M. Aglietta, B. Alpat, E.D. Alyea, P. Antonioli and etc* Multiple muon events observed in the LVD experiment, Nuclear Physics B - Proceedings Supplements, 35, 243-245. (1994)