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OPTIMAL STRATEGY FOR THE SEARCH OF COINCIDENT EVENTS BETWEEN EXPLORER AND NAUTILUS

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Abstract

In order to compare the efficiency of two different acquisition times for the detection of coincident pulse signals, analyses of real data of the bar-detectors are performed. For each of the two gravitational wave detectors, EXPLORER and NAUTILUS, statistical results on coincident signals wIth selected cosmic ray events are presented for 3.2 ms and $200\ \mu s$ sampling times of acquisition.

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1 Introduction

The principal problem searching for coincident events detected by the gravitational wave antennas EXPLORER and NAUTILUS arises, as well known since the Weber time, from the very large number of *candidate events* for each detector and, subsequently, from the large number of accidental coincidences.

The candidate events are determined by imposing a threshold on the data filtered with optimum filter matched to *delta-signals*. The threshold is referred to the signal-to-noise ratio.

$$SNR = \frac{E}{T_{eff}} \tag{1}$$

where E is the energy of the event and T_{eff} is the noise. Usually the threshold is put at

$$SNR_t = 19.5 \tag{2}$$

a threshold conveniently used in the past years in order to limit the number of candidate events.

In the last few years in the ROG group we have recorded and filtered the data with a sampling time of 3.2 ms which well complies with the detector bandwidth, order of 9 Hz, corresponding to a decay time of the event energy

$$\tau_o = \frac{1}{2\beta_3} = \frac{1}{2\pi\, 9Hz} \sim 20\ ms \tag{3}$$

However, it has been realized that with a sampling time of 3.2 ms some events could have been missed, and also that the energy of the detected events (the maximum value of the filtered data above threshold) had a relatively large error. For this reason the filtering procedure has been implemented, so to produce a sampling time of $200\ \mu s$.

The effects of this new procedure have been:

• b) a more accurate evaluation both in event energy and time;

• a) the production, for the same threshold, of a larger number of candidate events with respect to the 3.2 ms procedure.

While, undoubtedly, a) is an improvement, because it allows a better comparison between the energies of the coincident events (energy filter), b) increases the number of accidental coincidences, in that way the real signals could be submerged.

In our opinion to evaluate the efficiency of a procedure the important quantity to consider is

$$R = \frac{number\ (coincidences(\delta t) - accidentals(\delta t))}{sqrt(number\ of\ accidentals(\delta t))} \tag{4}$$

where δt is the sampling time. Both numerator and denominator depend on the sampling time, not necessarily R.

Table 1: Coincidences between CR and GW for EXPLORER. Threshold $SNR_t = 16$, down multiplicity for the cosmic rays $M = 50\frac{particles}{m^2}$. N is the total number of candidate events, n_c is the number of coincidences and $\bar{n}$ is the average number of the accidentals.

δt	N	n_c	$\bar{n}$
3.2 ms	295280	52	17.2
$200\mu s$	665940	82	38.4

Table 2: As in the Table1, for NAUTILUS.

δt	N	n_c	$\bar{n}$
3.2 ms	428270	36	15.3
$200\mu s$	1137700	77	38.6

In order to study this problem we make use of the real data and real signals induced by cosmic rays. On both EXPLORER and NAUTILUS cosmic ray detectors are installed. The cosmic rays generate in the bar-detectors delta-like signals with amplitude ranging from extremely small, to small and relatively large with respect to noise [1–4].

So it is possible to analyze the bar-detector response as function of incident energy. The recent, intense experimental activity about that effect is producing a lot of important results which make EXPLORER and NAUTILUS unique, as operating gravitational wave detectors. For instance, we remark on the calibration with respect to a mechanical impulse, even observing vibrations much smaller than brownian noise.

2 Using cosmic rays

During 2004 we have both the 3.2 ms and $200\mu s$ filtered data for EXPLORER and NAUTILUS. The search for coincidences between the cosmic ray apparatus (CR) and the corresponding gravitational wave detector (GW) has given the result shown in the Tables 1 and 2, with a coincidence window of $w = \pm 10\ ms$. We notice that with the 200 μs sampling the number of candidate events increases, as expected.

The result is also given in terms of number of coincidences n_c and average accidentals $\bar{n}$ versus the multiplicity, as shown in fig.1,for the threshold $SNR_t = 16$.

In fig.2 we present the result of the coincidence search versus the threshold of the variable SNR, as defined in Eq.1, the multiplicity $M = 50\frac{particles}{m^2}$. In both figs.1 and 2 we notice that the coincidences are well above the noise determined by the number of the accidentals, and that both coincidences and accidentals increase for the fastest sampling.

In order to understand which is the most convenient sampling time to use, we have

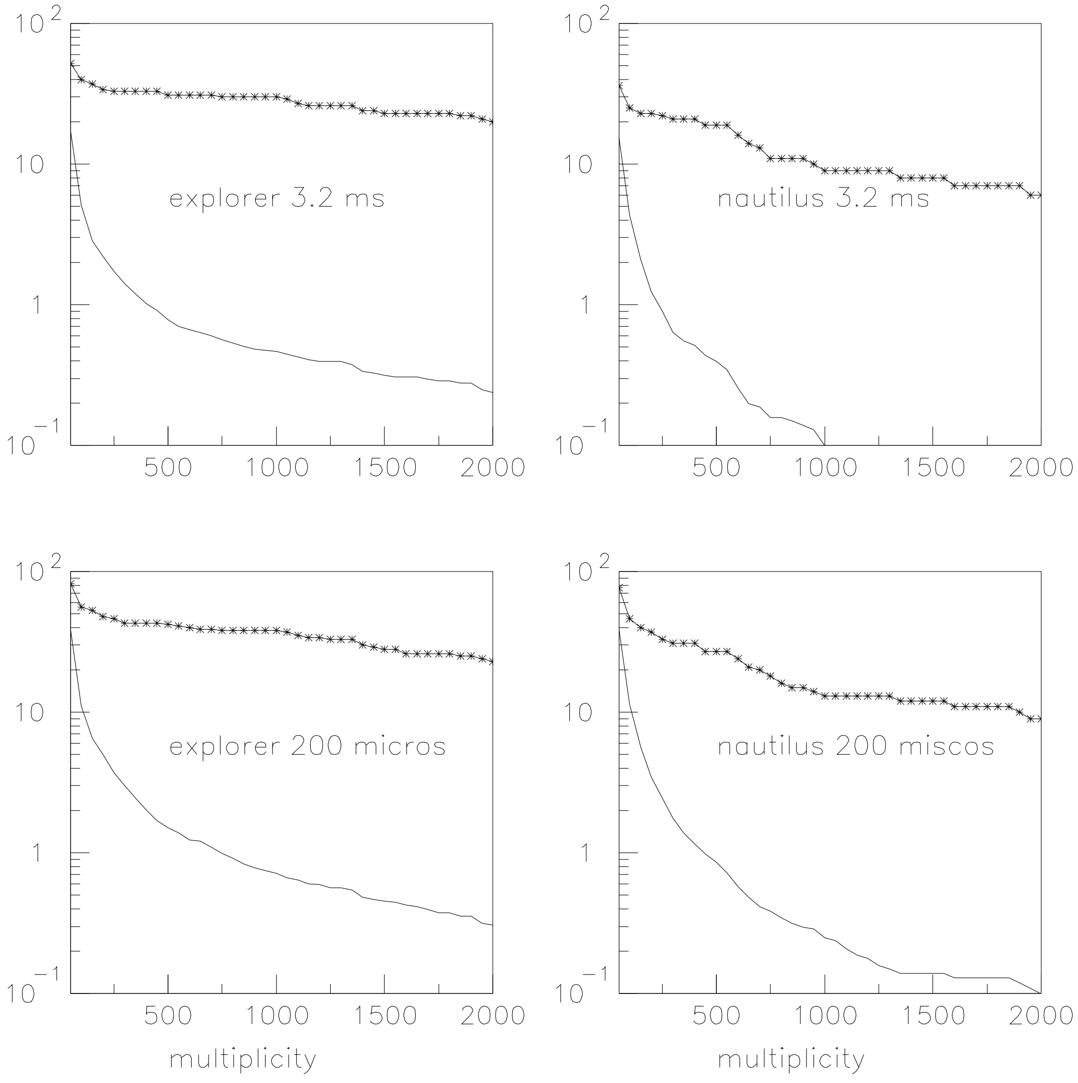

Figure 1: Number of coincidences n_c (asterisks) and average accidentals $\bar{n}$ (simple line)versus the multiplicity, for the threshold $SNR_t = 16$.

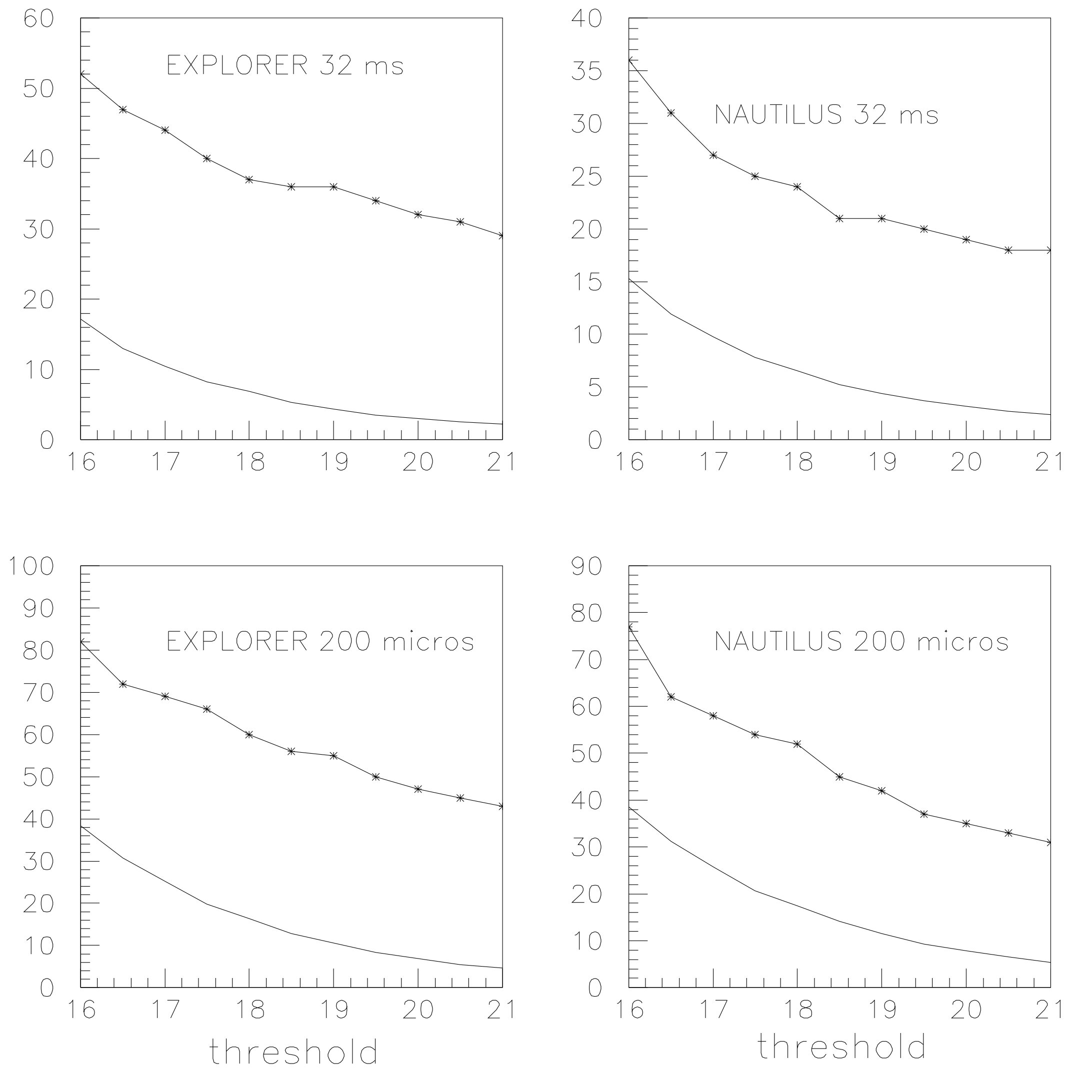

Figure 2: Number of coincidences n_c and average accidentals $\bar{n}$ versus the threshold for the multiplicity $M = 50$.

calculated the ratio

$$R = \frac{n_c - \bar{n}}{\sqrt{\bar{n}}} \tag{5}$$

We show in fig. 3 the above quantity R versus the threshold SNR_t and in fig.4 we show R versus the multiplicity M

Finally, in fig.5 we show the ratio of the event energy obtained with the $200\ \mu s$ to that of the common events obtained with the 3.2 ms sampling time. As expected the ratio is always greater than one, apparently independent on the event energy.

3 Discussion and optimal strategy

It is evident that with the smallest sampling time we find more events due to true signals, and also that the energy has to be preferred. However, we have found that the number of events increases very much and so the accidental coincidences. We found that, for cosmic rays, the use of the fastest sampling time does not improve the efficiency of detection, as shown in figs. 3 and 4.

In the case we have considered with several events due to cosmic rays the use of the fastest sampling could be more convenient. This is not true in the case of gravitational waves, because the number of accidentals using the fastest sampling in both EXPLORER and NAUTILUS will be much higher (the accidentals surely increase as the product of the rates, while the possible signals could increase but not quadratically).

We believe that the best strategy for the coincidence search is to take, for each detector, the events in common in the two event-lists obtained with the slow and with the fast sampling. Then to consider the energy and timing obtained with the fastest sampling. This will improve the efficiency of the energy filter and reduce the number of events used for the coincidence search.

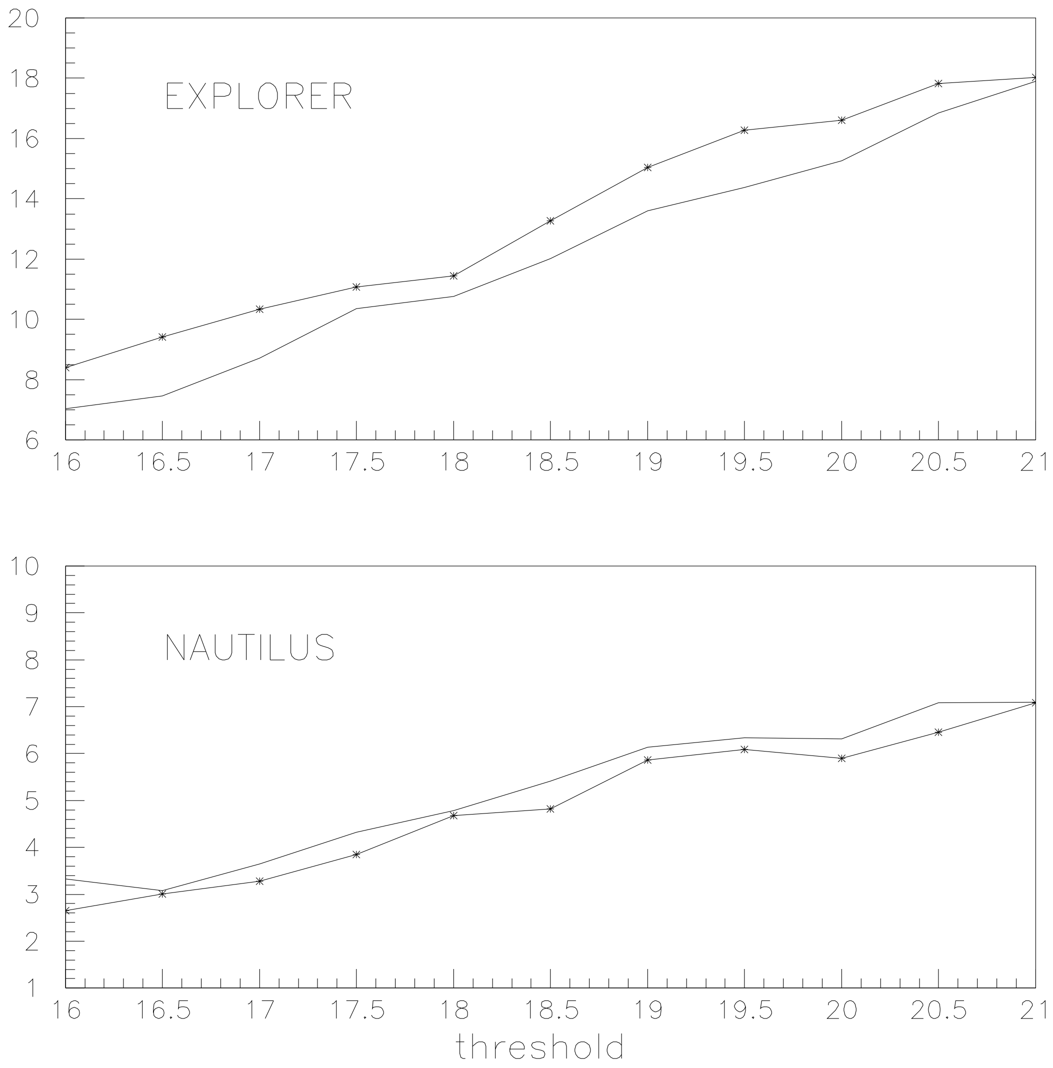

Figure 3: The ratio R versus the threshold SNR_t. The asterisks refer to the 3.2 ms sampling time.

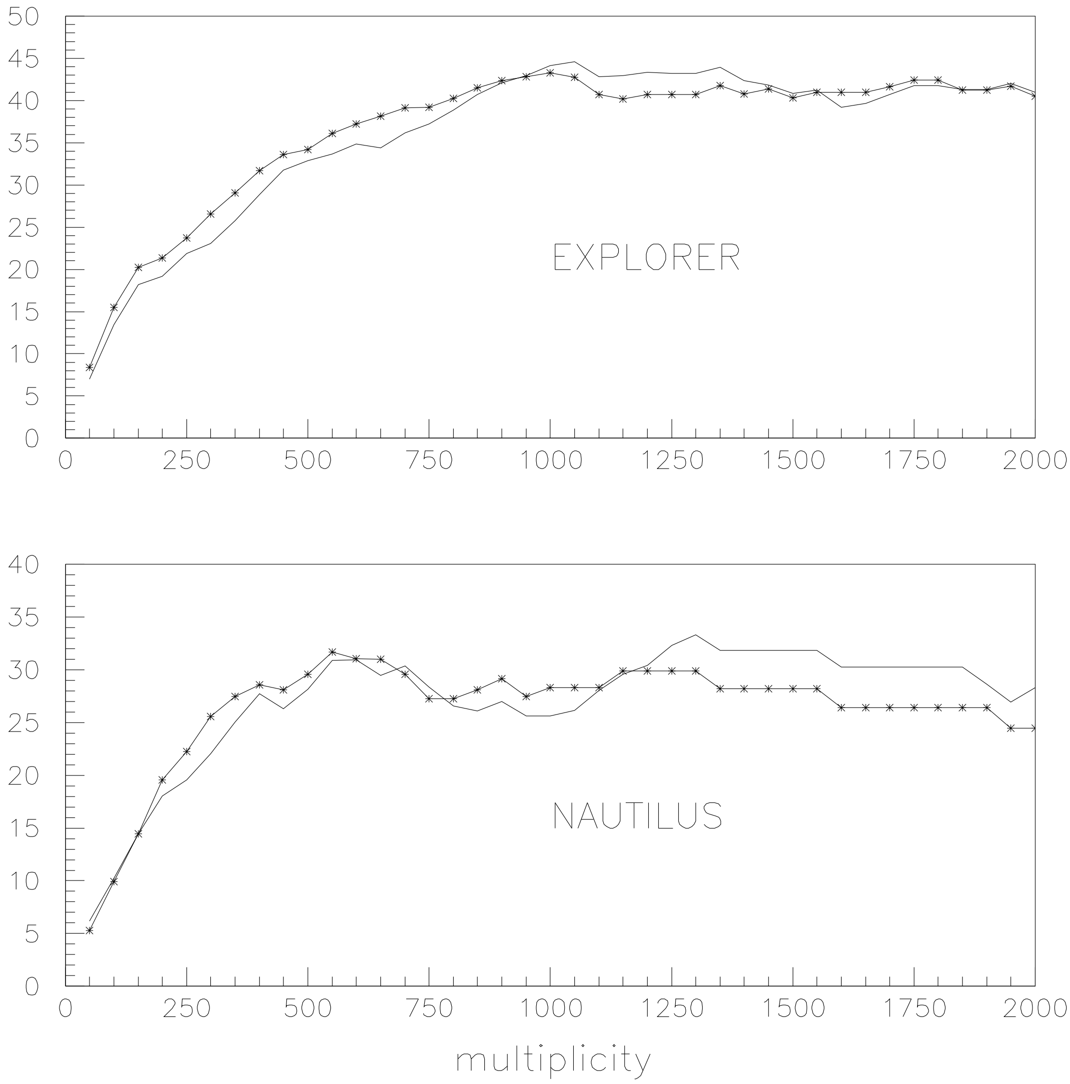

Figure 4: The ratio R versus the multiplicity M. The asterisks refer to the 3.2 ms sampling time.

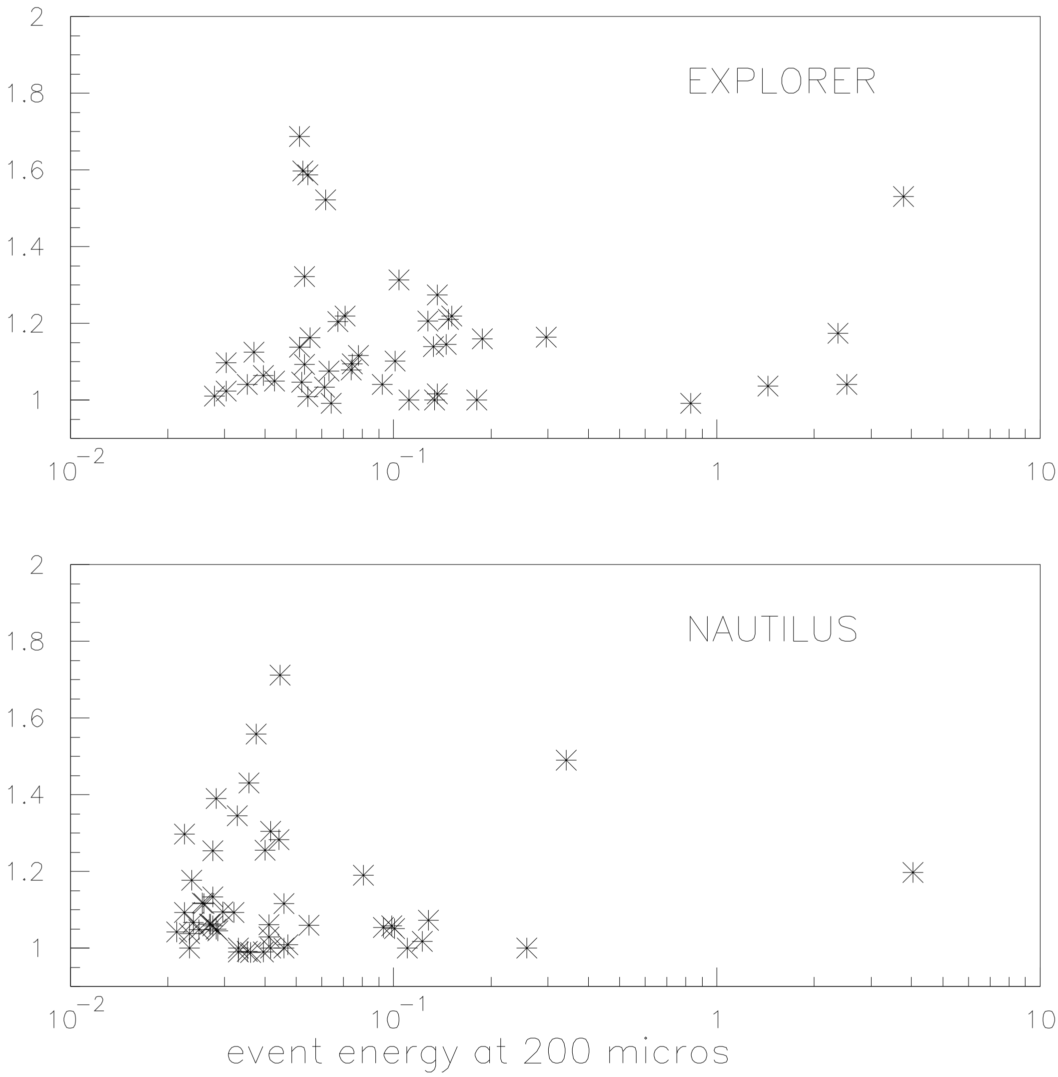

Figure 5: The ratio of the event energy obtained with the 200 μs to that obtained with the 3.2 ms sampling time. There are 46 common events for EXPLORER and 49 common events for NAUTILUS.

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