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Seasonal fluctuation in neutron yield underground measurements

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The aim of this letter is to present evidence of a seasonal fluctuation in the measurements of the neutron field obtained in two different underground laboratories. We used two very similar liquid scintillator detectors applying the same pulse shape discrimination technique of the photomultiplier signals. In a previous paper [1] we presented the results of neutron detection, obtained by a 32 liters organic liquid scintillator (Aromatic Hydrocarbon BC-501A) home made detector. Data have been recorded in LNGS hall C (3800 m.w.e.) since August 1997 until April 1998. In another paper [2] the measures done in Baradello underground site (300 m.w.e.) in North Italy since May 2002 until September 2002 with a smaller detector (one liter only) are discussed. We analysed the data collected in both experiments and we have found a seasonal fluctuation of the signals attributed to proton recoils. The analyses over a long period (many months) require usually an accurate energy calibration procedure to have a good control of systematic errors and to assure the stability of the various experimental parameters, which might mimic periodic variations of the signals. The energy has been calibrated with high accuracy by means of the alpha particles produced by alpha decay of Th and U impurities contaminating the scintillating material ($\approx 10^{-12}$ atom/atom). Four alpha particle energies [1] are used in the hypothesis that the contaminants be an U-Th mixture at equilibrium with daughters. The pulse distribution has been fitted to a sum of four Gaussians grouping the data in periods of about 10 days. The resulting peak positions are used to derive the calibration curve, i.e. the relation between alpha energy and ADC counts (see Appendix A). By means of this procedure the data become almost independent from any kind of electronic instability. The alpha particle contamination constitutes more than 90% of the events, but they are confined in the low energy region and the remaining events were attributed to neutron interactions, as we observed in a calibration run with neutron beams provided by the neutron beam facility installed at Physikalisch-Technische-Bundesanstalt at Braunschweig (Germany) [3]. Therefore in order to select "alpha" signals we choose a sub-sample with the proton-equivalent energy in the range 1 to 3 MeV, whereas the selection of "neutron" events is obtained fixing the lower threshold at 3.5 MeV, a region in which alpha particles are absent. The time modulation analysis has been done on these two selected samples.

In Figure 1 the mean deviation of "alpha" rate (R - <R>) / R taken at LNGS, which appear to be roughly constant with respect to the time since August 1997 until April 1998, is shown as a function of the time. Of course we do not expect any fluctuation in the alpha particle production. An exponential fit done on the absolute rates shows a slightly decreasing behaviour (half-life about 17±3 years) due probably to ageing of the scintillating liquid or to a ^{210}Pb contamination (22.3 years mean-life) of the scintillating liquid during the manufacture phases. The observed stability is within 1 % in six months, assuring to be able to put in evidence even small annual fluctuations, if any. The mean "alpha" signal rate is <R> = 0.108 Hz in the full detector over the 250 day period. In Figure 2 the time dependence of the "neutron" mean rate deviation, measured at LNGS, is shown (full circles left scale). The data are grouped in periods

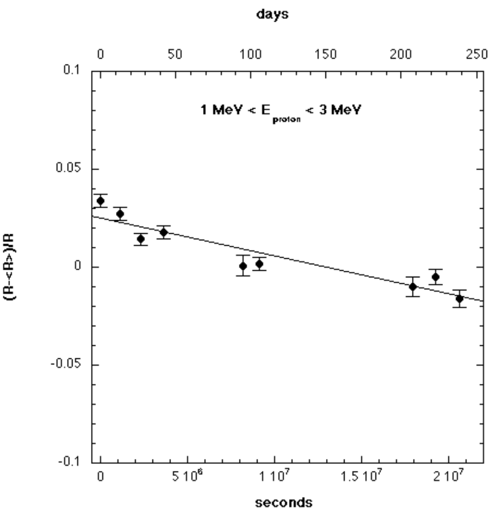

Fig. 1 "Alpha" signal: the mean rate deviation (R-<R>)/R versus time at LNGS. The line is the result of a linear fit. The mean deviation of the points is within 1%.

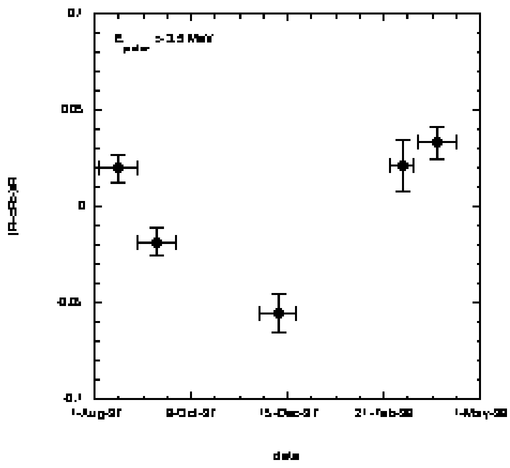

Fig. 2 "Neutron" signal: the mean rate deviation (R-<R>)/R versus time at LNGS.

of about 30 days in order to keep small the statistical error. Unfortunately there are two periods in which no data have been collected, causing a crucial lack of information. Any way one observes the evidence of a seasonal modulation in the "neutron" yield (10.6 ± 1.6 % effect in a six months period). The mean "neutron" rate is 0.0123 Hz / 32 liters,. Very similar measurements [2] have been collected also in the Baradello underground site. The same technique and scintillating liquid (one liter only) have produced the data shown in fig. 3, which are grouped in periods of about 20 days. The mean "neutron" rate is 2 10^{-4} Hz / liter. The "alpha" background is still independent of the time while the effect of seasonal variation of "neutrons" seems to be more pronounced at Baradello site then at LNGS. It is worth noting the same maximum rate in summer both in Baradello and LNGS laboratories.
These results suggest that a correlation between "neutron" flux intensity and season may exist in both underground laboratories, however the statistics is a little bit poor in order to be conclusive about this point. The cause of this seasonal phenomenon is not yet completely known. Several researchers suggest that a variation of the radon flux from the soil could give an explanation of the effect.

Another possible interpretation of this effect could arise from the fact that a component of the neutron flux consists of cosmic muon induced neutrons and it is well known the seasonal variation of the muon flux [4]. Unfortunately the measured yield of the cosmic neutrons at different depth in underground sites [5] is too small to account for the fluctuation seen in our data.
Being the effect not well understandable at present, we suggest therefore that new measurements, to be collected continuously in a 12 months period at least, would be necessary in order to get more information about this unusual behaviour.

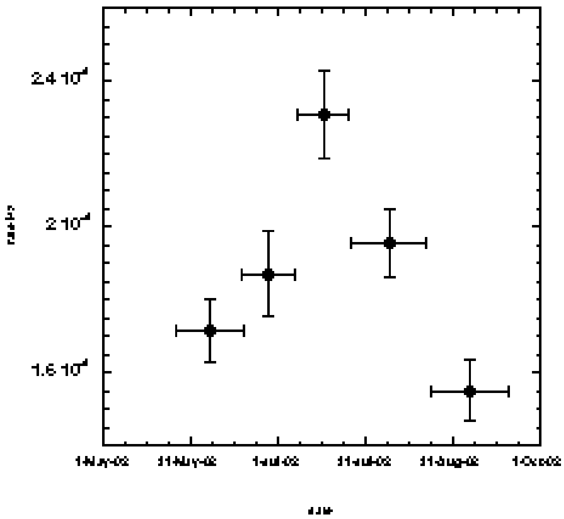

fig. 3 "Neutron rate at Baradello underground site.

Appendix A

The summary of data taken at LNGS is shown in Table. The runs 5 and 13 are taken with a neutron source and are obviously not considered in the analysis. The runs 9 to

Run number	Run date	Run time (days)	Run time grouped (days)	Number of recorded triggers	Note
1	11-8-97	10.165	19.0732	1.046e+05	
2	24-8-97	8.9082		91558	
3	7-9-97	10.909	22.861	1.136e+05	
4	22-9-97	11.952		1.085e+05	
5	15-10-97	16.260		1.527e+05	Neutron source
6	6-11-97	6.7750		63617	data with bad dead time
7	14-11-97	3.6939	13.4687	39347	
8	25-11-97	9.7748		1.000e+05	
9	7-12-97	8.7317		76304	Absorber
10	22-12-97	9.3964		80097	Absorber
11	7-1-98	10.916		86378	Absorber
12	22-1-98	9.4310		82618	Absorber
13	5-2-98	5.2987		42101	Neutron source
14	7-3-98	4.9040	4.90	52521	
15	22-3-98	7.8908	14.01	79254	
16	7-4-98	6.1199		60843	

12 are taken with a neutron absorber put around the detector and are therefore not considered in the analysis. The data of run 6 have troubles in the dead time determination, due probably to electronic problems so they are not useful.

We have calibrated in energy one at a time 16 groups (see Table) of about 10 days each, in order to reduce the possible electronic instabilities. The energy calibration (see fig. 4) has been done on the ADC spectra fitting four Gaussians peaked at the alpha energies (4.75, 5.40, 6.00 and 7.00 MeV) with the areas constrained at equilibrium (from U and daughters contamination inside the scintillating liquid). The result of the fit, for one typical cell, is shown in fig. 5, where ADC counts versus alpha energies are plotted. We made use of a power law

$$ADC(counts) = a \cdot E_{alpha}{}^{b} (MeV)$$

$$E_{proton} = 0.266 \cdot E_{alpha}{}^{1.2} (MeV)$$

in the fit and we have used in the subsequently analyses the fitted calibration parameters *a* and *b* in each experimental sample.

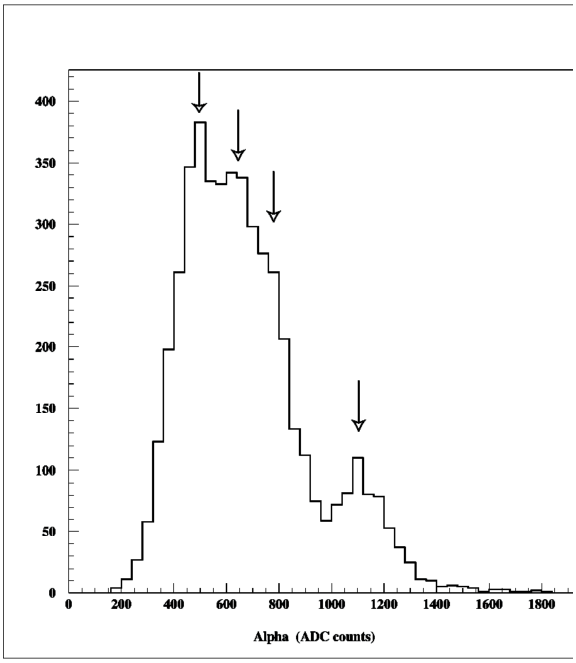

fig. 4 Energy spectrum in ADC counts

The analysis has been done with 5 samples obtained grouping the data (see Table) in five blocks in order to reduce the statistical error.

References

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[4] M.Ambrosio et al. Astropart. Phys. 7 (1997) 109

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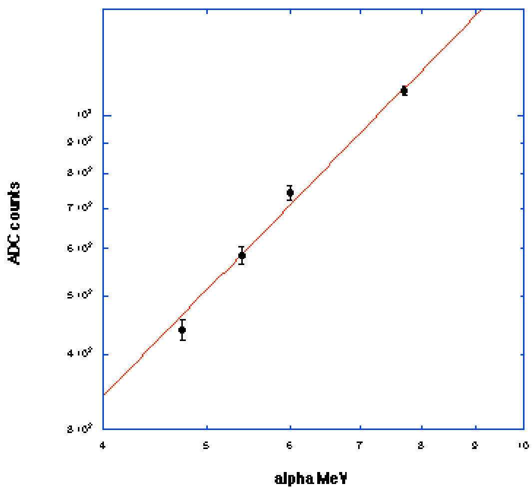

fig. 5 ADC counts versus alpha energy (MeV) four energies. The fit is done with a power law.

[5] F.Boehm et al. Phys. Rev. D, 62 092005 (2000)
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