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ANALYSIS OF NEUTRON AND MUON COUNTING DURING A FORBUSH DECREASE

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Abstract

Data measured with a small Geiger counter during a Forbush decrease were compared to neutron and muon fluxes reported by professional monitor stations. Correlation between neutron and muon rates was studied and compared to results obtained outside the Forbush decrease.

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1 MOTIVATIONS

Forbush decreases are known as impressive transient changes in the cosmic ray intensity. They are characterized by a rapid (a few hours) intensity reduction, followed by a slow recovery (a few days). Since their discovery [1], it is generally believed that such strong variations are related to solar flares-associated interplanetary disturbances. However, several phenomena related to magnetic disturbances, which may produce such intensity decreases, have been discussed over the years, and there is considerable disagreement concerning the detailed features of such structures [2].

Monitoring of Forbush decreases is usually done through neutron monitor stations, since most of the intensity variation is associated to low energy particles, whereas GeV muons are sensitive to more energetic primaries. This means that such effects are more difficult to see with muon detectors, especially if they have small counting rates. To suggest a quantitative study of such effects for educational purposes, a correlation analysis between neutron counting rates from neutron monitor stations, the muon counting rate from a small Geiger counter and the muon rate from a muon telescope was carried out, following a Forbush decrease on November 7^{th}, 2004. The results obtained for such period were also compared to the standard correlation obtained outside the Forbush event.

2 EXPERIMENTAL RESULTS

Figs. 1 and 2 show the neutron fluxes during November 2004, as reported from the Oulu (Finland) [3] and Moscow [4] neutron stations, which continuously update and make available the measured data in small time steps. A two-steps Forbush decrease is seen in both spectra starting on November 7^{th}, with a large reduction of the neutron flux, recovering in about one week.

The Geiger experimental set-up used in the present experiment has been already described in previous educational investigations [5-6]. The Geiger counting rate was about 0.3 Hz. The data were collected in 30 minutes steps, from November 9^{th} (14:30 UTC) to November 15^{th} (14:30 UTC) just at the beginning of the second Forbush decrease. We considered as a reference also a larger set of data, collected from April 9^{th} to July 17^{th}. All the data were corrected for the barometric effect [7] before carrying out any correlation analysis.

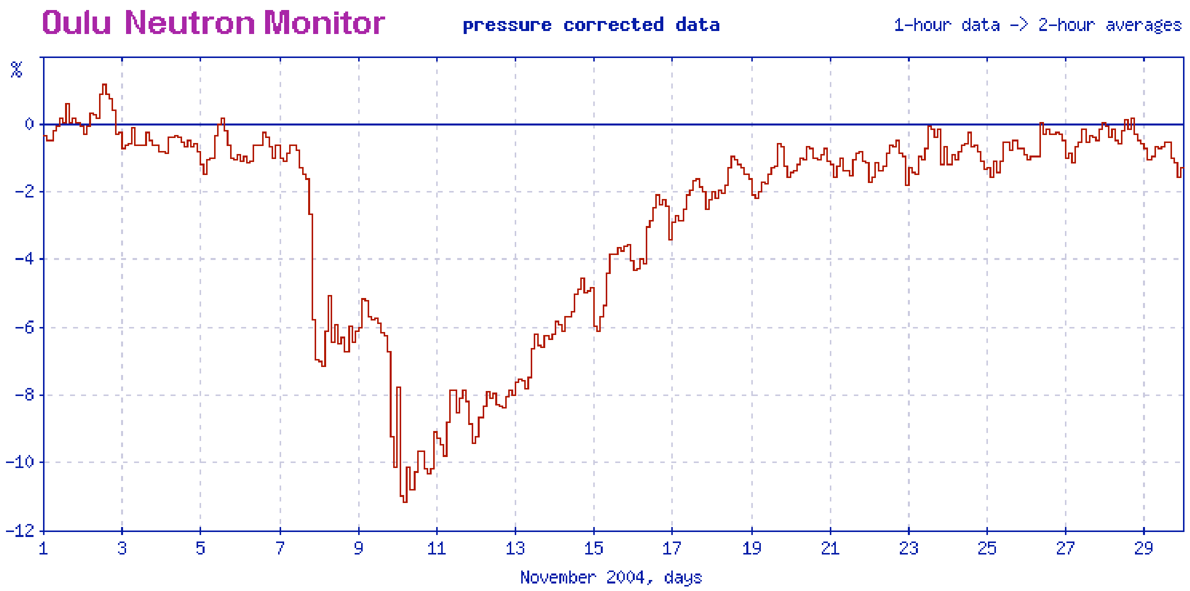

Fig1: Neutron flux measured at the Oulu neutron station [3] during November 2004.

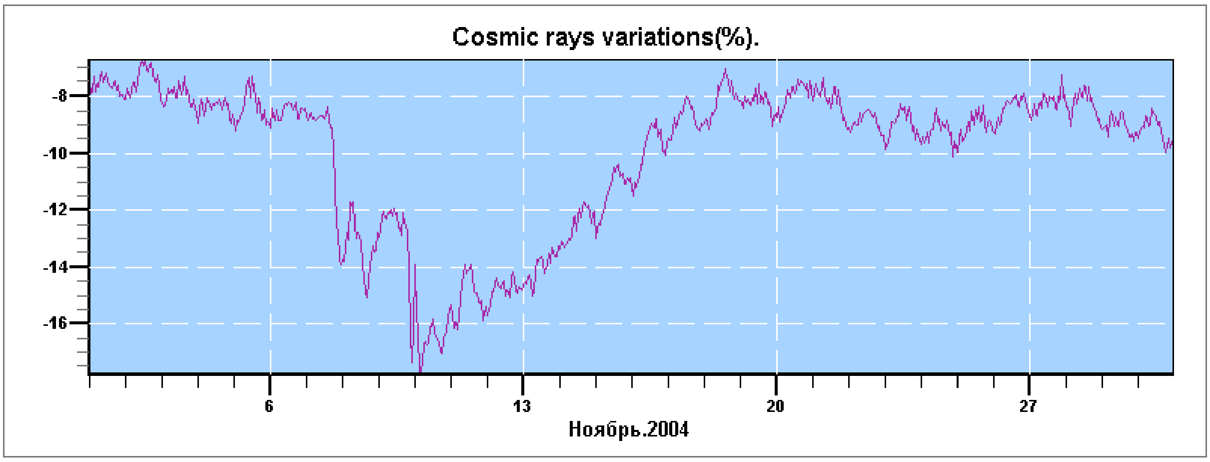

Fig.2 : Neutron flux measured at the Moscow Neutron Station [4] during November 2004.

3 CORRELATION ANALYSIS

Fig.3 shows a comparison of the count rate obtained through the small Geiger counter with the two hourly neutron fluxes. The origin was taken here as November 9th (14:30 UTC).

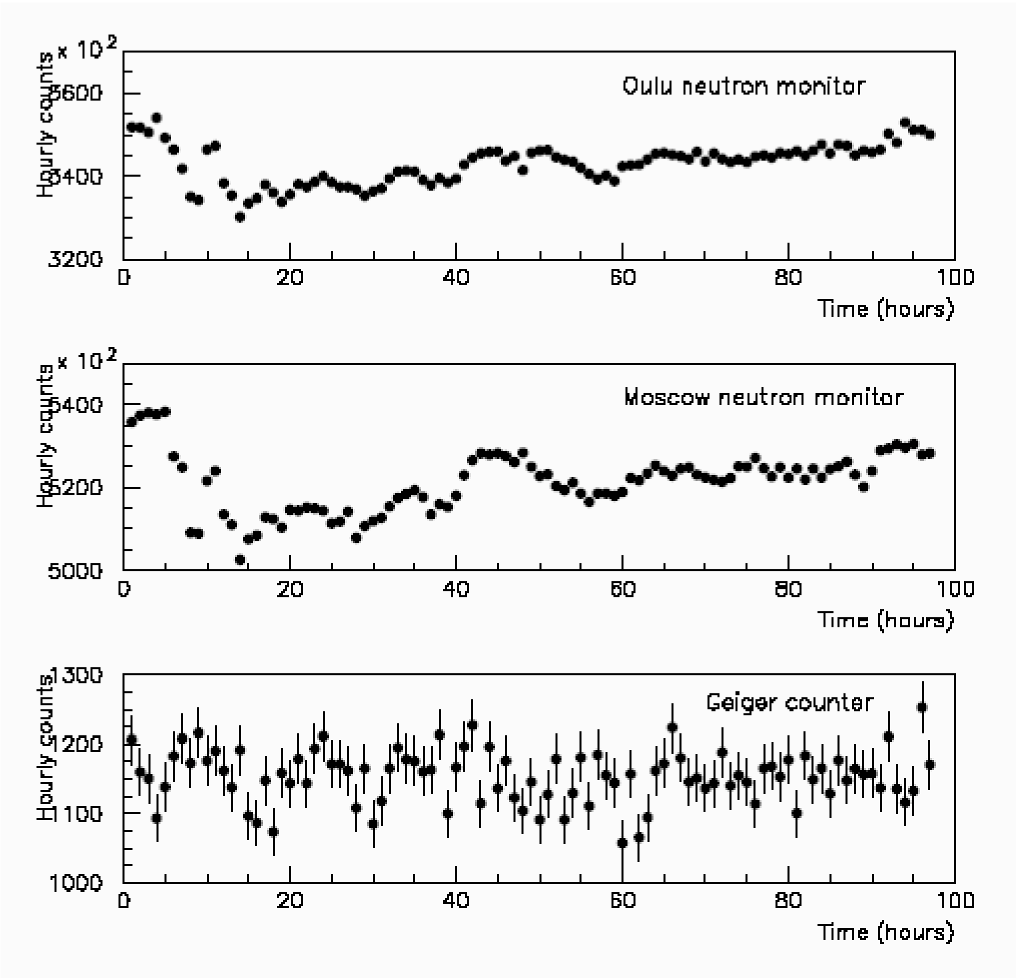

Fig.3: Hourly values of the two neutron monitor stations, compared to the Geiger counting rate. The origin was taken at November 9th 2004 (14:30 UTC).

Statistical errors on the small Geiger counter are apparent, due to the small volume of such detector. The two monitor stations give correlated patterns as a function of time. A correlation scatter plot is shown in fig.4. The data from these two stations give a correlation coefficient of 0.927 for the period under consideration.

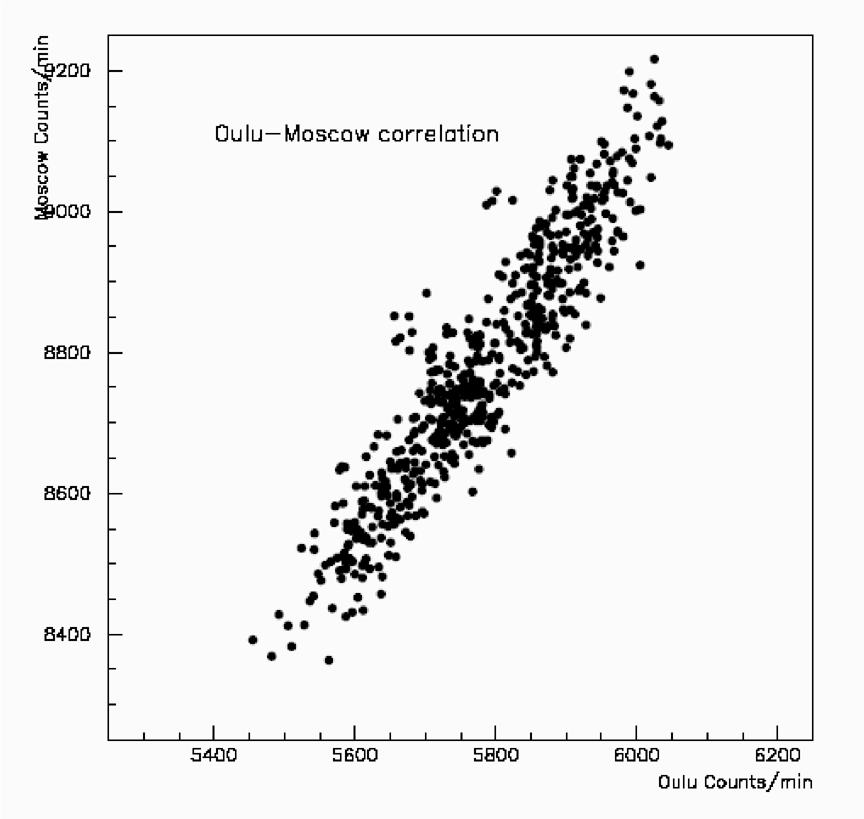

Fig.4: Scatter plot of the Oulu and Moscow neutron fluxes (counts/min).The data give a correlation coefficient of 0.927 for the period under consideration.

The correlogram obtained by shifting one of the two time series with respect to the other one is shown in fig.5 and it is seen that the correlation disappears in a time scale of the order of a few hours. Large values of the cross-correlation coefficient after a long time (i.e. 40 h) are simply the result of the particular trend in that period and are not considered as a periodic behaviour.

The correlation between the count rate in the small Geiger counter and the two neutron stations is very poor, with values of r=0.07 (correlation with Oulu station) and r=0.04 (correlation with Moscow station), resulting from N=97 hourly values (about 4 days). During a long period (100 days), outside any Forbush decrease, the correlation between the average daily values from the same Geiger counter and the Moscow neutron station gave r=0.20 (N=100 values), which is at the limit to be considered as significant, although larger than the values obtained during the Forbush decrease. For a further check of the correlation between

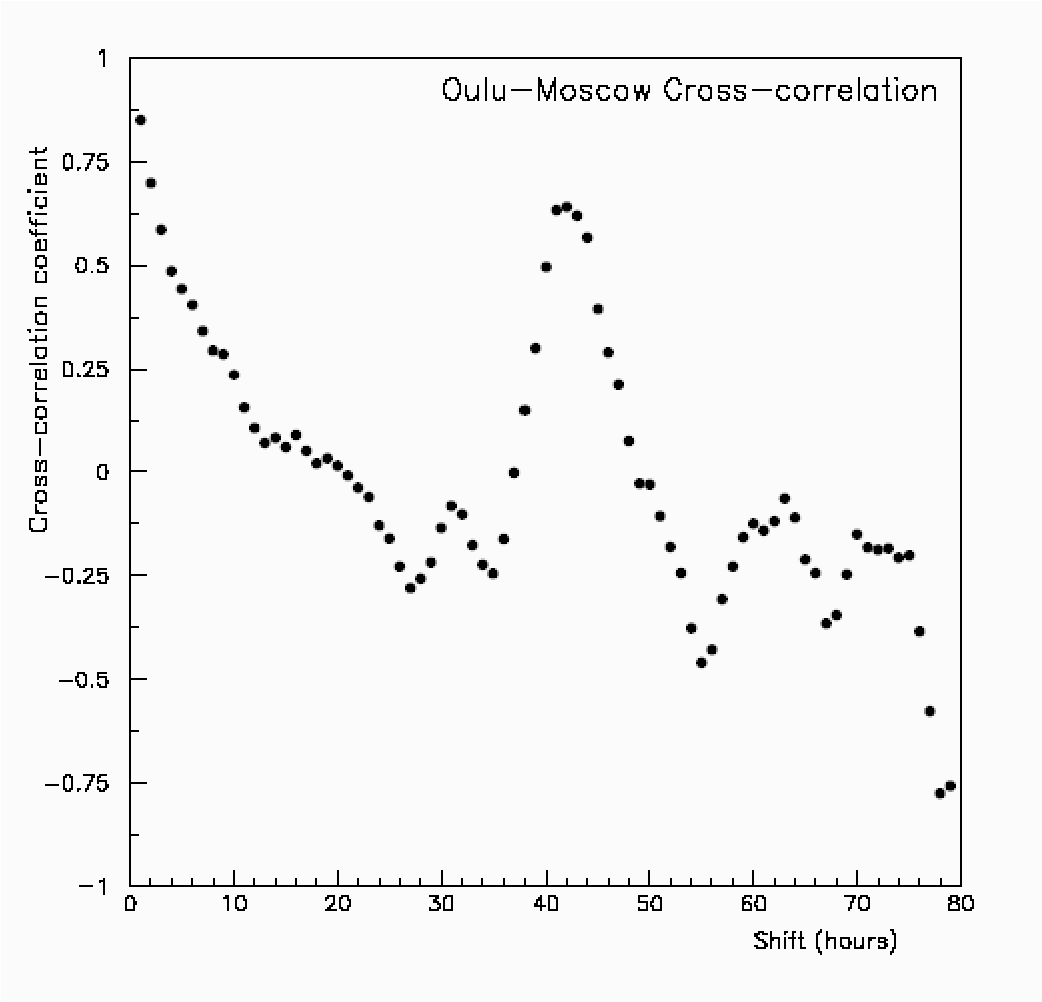

Fig.5: Correlogram plot of the Oulu and Moscow neutron fluxes.

muon and neutron counts during a Forbush event, we considered muon data measured with a larger statistics from the Adelaide muon telescope [8]. Due to some lack of data from the Adelaide muon telescope, we only considered the period from November 1 to 26, which spans the Forbush event under consideration. Data from such telescope were corrected for the barometric effect, assuming a value of the barometric coefficient equal to 0.12%/mbar, taking into account the average value of the atmospheric pressure in that period. Once corrected for the atmospheric pressure, data from the Adelaide muon telescope show a decrease of the muon flux in close coincidence with the effect observed in the neutron flux. However, the intensity changes by only about 5 %, whereas a decrease in the order of 10% is observed in the neutron intensity, as it is shown in Fig.6. Moreover, the recovery phase after the Forbush decrease shows a different trend in the two cases. The neutron intensity returns to the original (pre-Forbush) value in about one week after the minimum with a monotonic trend, while the muon flux shows a slower increase with time. The correlation between the two sets of data exhibits an overall correlation coefficient of 0.72 for the period from November 1 to 26. However the correlation is strongly different in the pre-Forbush, Forbush decrease, recovery phase and after-Forbush, as it can be seen from Figs.7 and 8, which show the overall correlation plot and subsets of data for selected time periods.

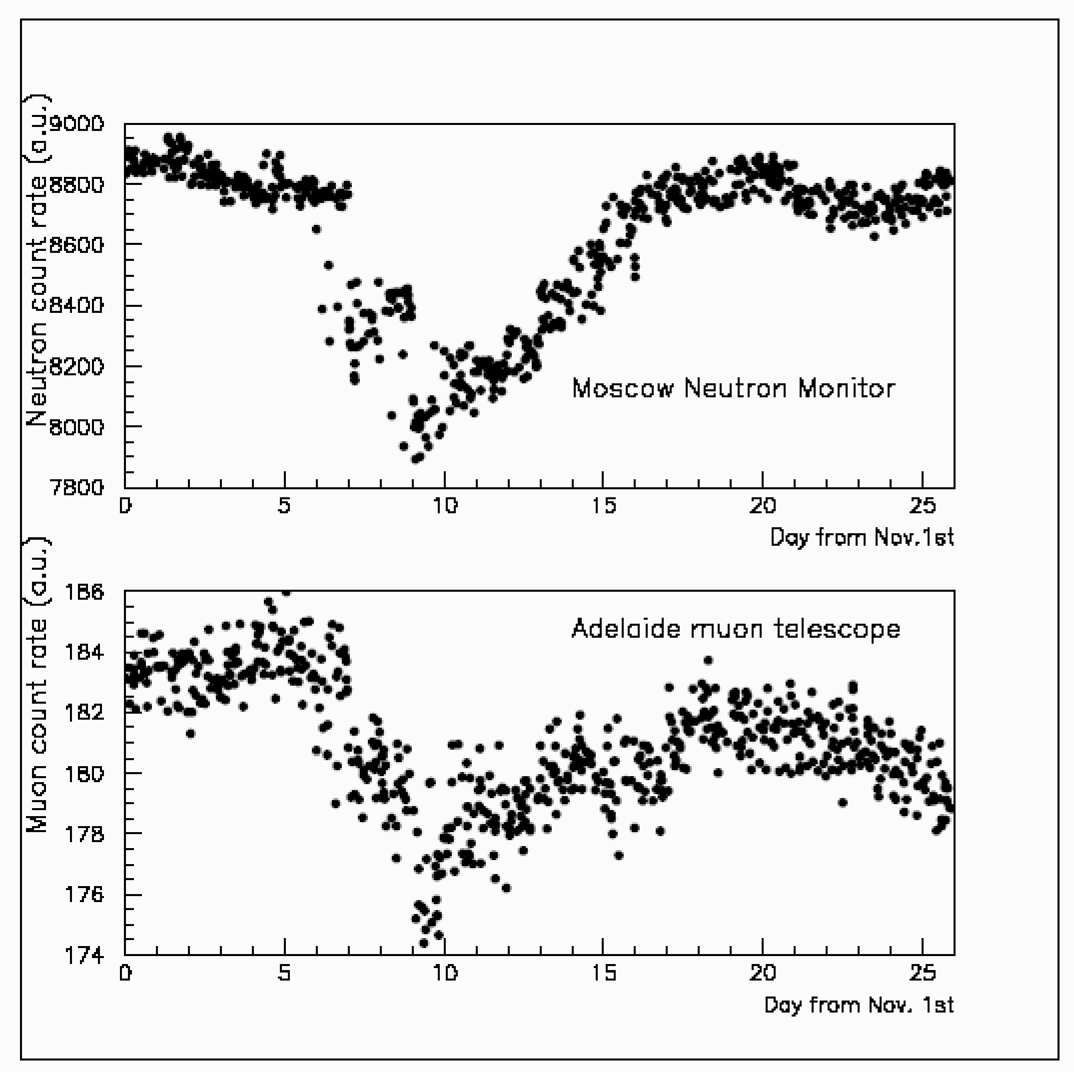

Fig.6: Neutron and muon fluxes as a function of time, for the period November 1-26, 2004, spanning the Forbush event under study.

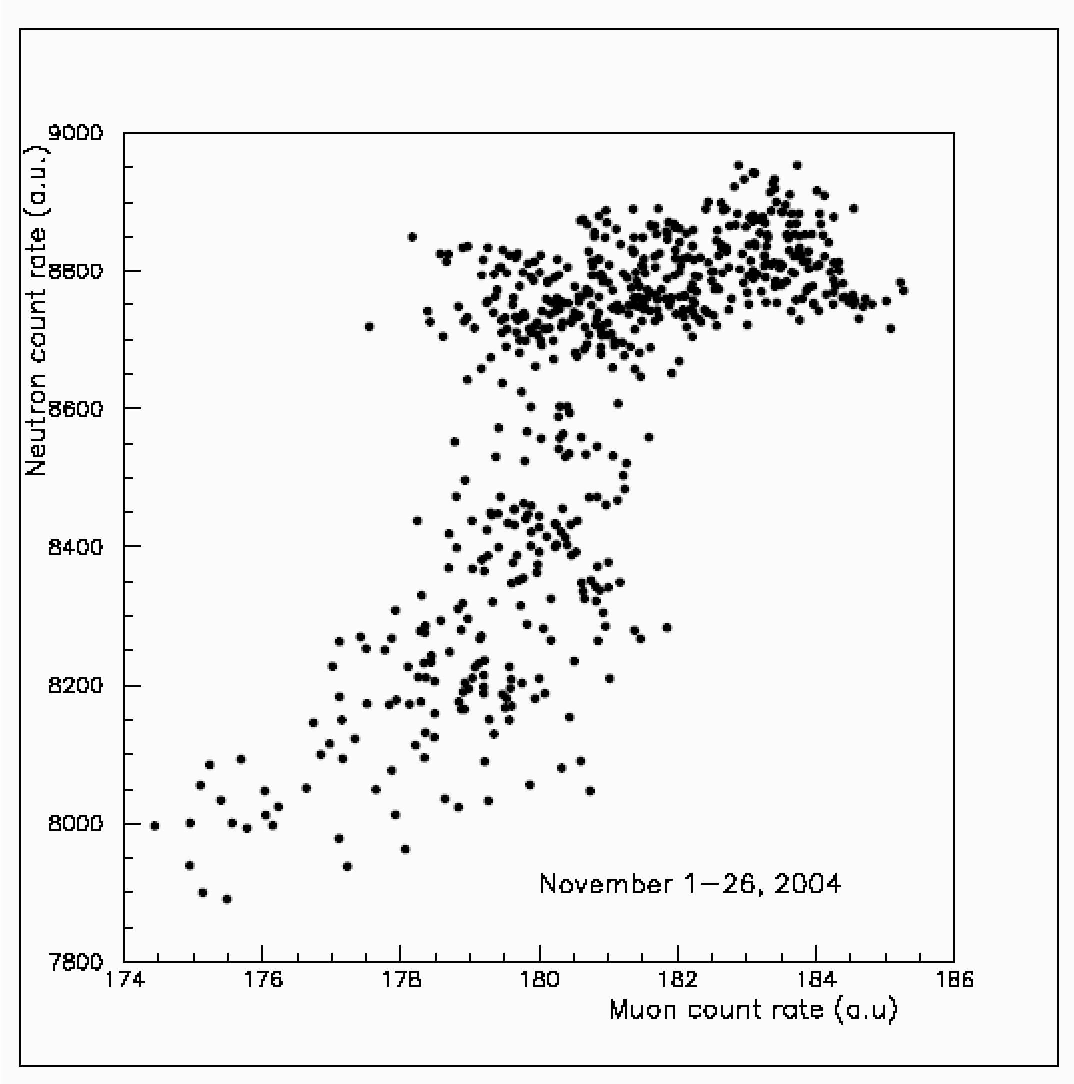

Fig.7: Correlation plot between neutron count rate (from the Moscow station) and muon count rate (from Adelaide muon telescope).

A quantitative analysis of such correlation was carried out evaluating the correlation coefficient r for periods of subsequent 5 days, starting from November 1st, and shifting such interval in steps of one day. The result is shown in Fig.9, where it appears that the correlation reaches its maximum from November 6 to 11, whereas it decreases to smaller values during the recovery phase. Different choices of the time interval over which to extract the correlation coefficient did not affect the main features of the effect. The decrease of the correlation during the recovery phase is clearly due to the different trend observed in the neutron and muon fluxes as a function of time. Outside the Forbush event, the correlation is very small, since only small variations are observed once the data are corrected for the atmospheric effects.

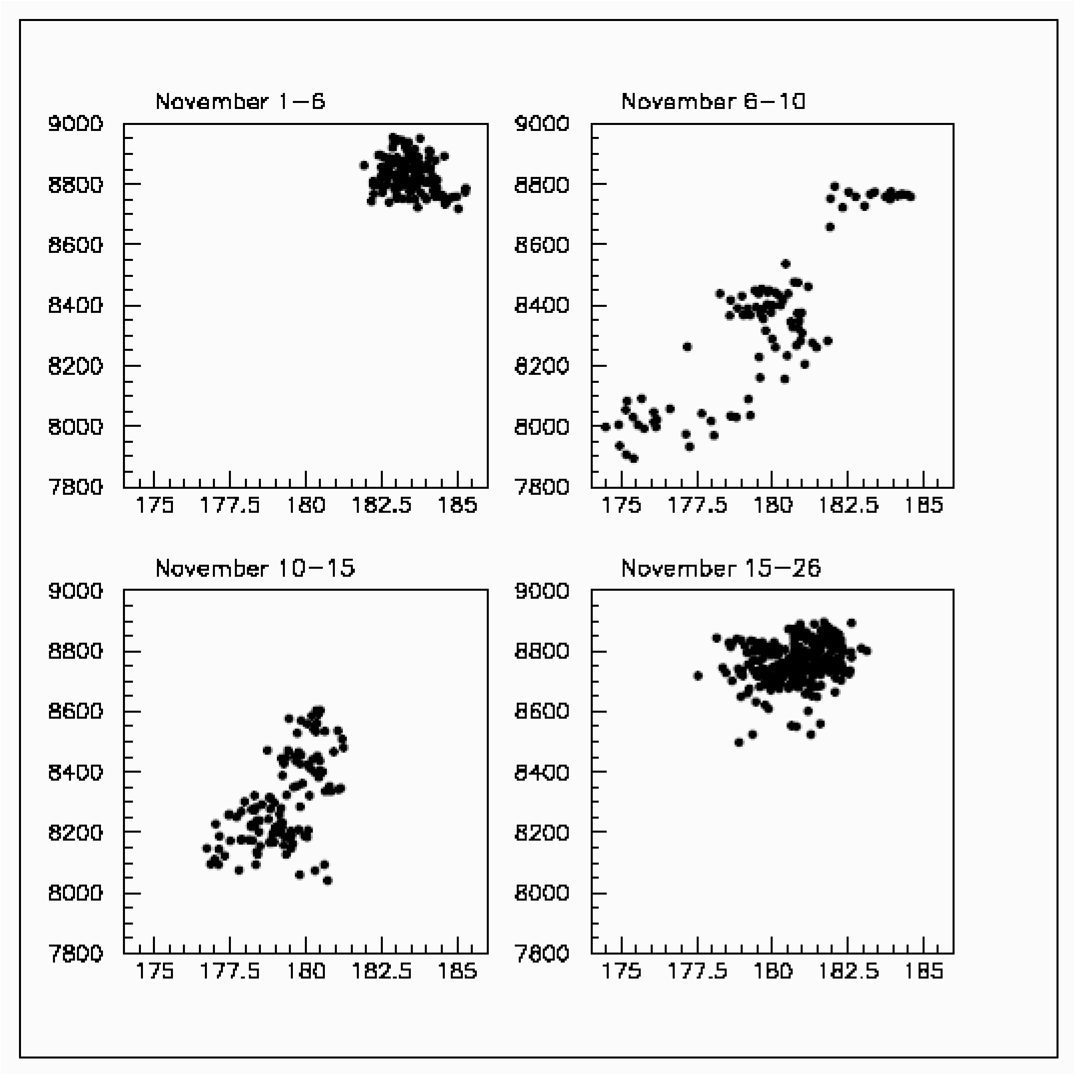

Fig.8: Correlation plot between neutron and muon count rates, for selected time intervals spanning the pre-Forbush phase (Nov.1-6), Forbush decrease (Nov. 6-10), recovery phase (Nov. 10-15), post-Forbush (Nov. 15-26).

4 CONCLUSIONS

A correlation analysis of neutron and muon counting rates from monitor stations was carried out with the aim to investigate the usefulness of cosmic ray educational activities which are even within the reach of high school teams. Professional data which are made available through the Web may be used as a good quality test case to apply quantitative data analysis, thus allowing high school teachers and students to face with the typical problems encountered in physics experiments. The use of a small Geiger counter may also result in a small set of data which can be compared to those extracted from professional stations. In case of Forbush strong variations in the cosmic ray intensity, the low statistics which can be obtained from a single small volume Geiger counter does not allow to directly see the effect, and some consideration can only be made concerning the degree of correlation during the different phases of the Forbush event. In such case unfortunately we could only study the last part of the Forbush event and its recovery and post-Forbush phase, while the period where the main intensity variation is observed could have shown a larger effect in the correlation coefficient. Additional investigations could be performed if long term monitoring of the Geiger count rate and atmospheric pressure will be achieved, possibly by the use of several Geiger counter operated in the same place or in different high schools which could share the obtained results to increase the statistical significance of the data.

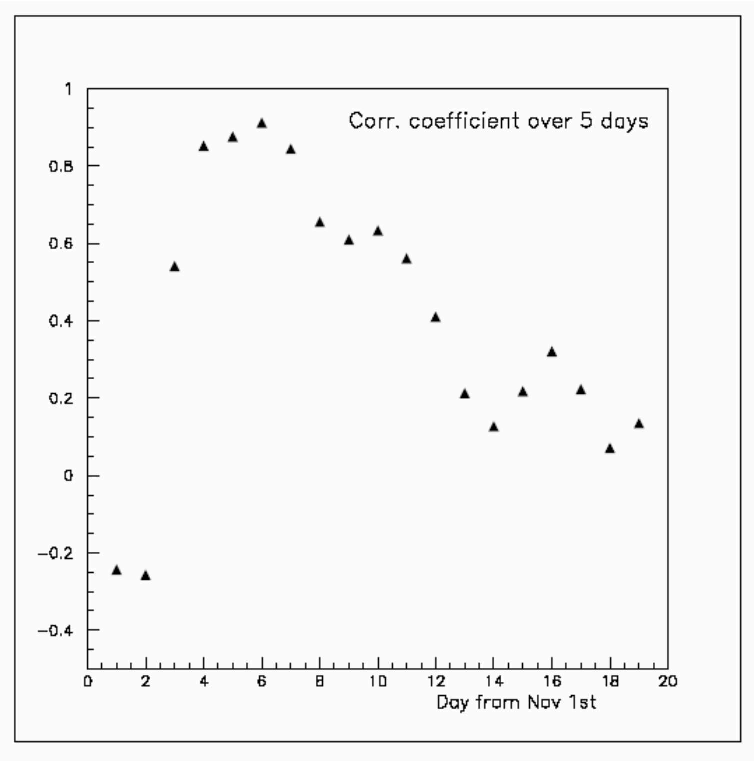

Fig.9: Correlation coefficient between the neutron and muon fluxes, evaluated for time intervals of 5 days, as a function of the starting time of each interval.

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