THE METHOD OF SOLAR NEUTRON SEARCH WITH PAMELA NEUTRON DETECTOR

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Fig. 1. Spectrometer PAMELA

Introduction. On the 15th of June 2006 Resurs-DK1 satellite with the magnetic spectrometer PAMELA on board was launched in orbit from Baikonur Cosmodrome. The Resurs-DK1 had a polar elliptic orbit of 350 – 610 km height with an inclination of 70,4° [1]. The neutron detector ND [2] was part of PAMELA instrument and served to improve the separation between electrons and protons registered by the calorimeter. ND represents the 36 cylindrical proportional counters filled with gas ^{3}He under the pressure of 7 atmospheres [2]. Two planes of 18 counters surrounded by a polyethylene moderator where neutrons are slowed down to thermal energies. After this neutrons were registered, the ND efficiency was about 10 %. ND had the background channel which recorded the total number of neutrons detected during time intervals between the particle triggers. In particular, data from the background channel were used to search for solar neutrons [3, 4].

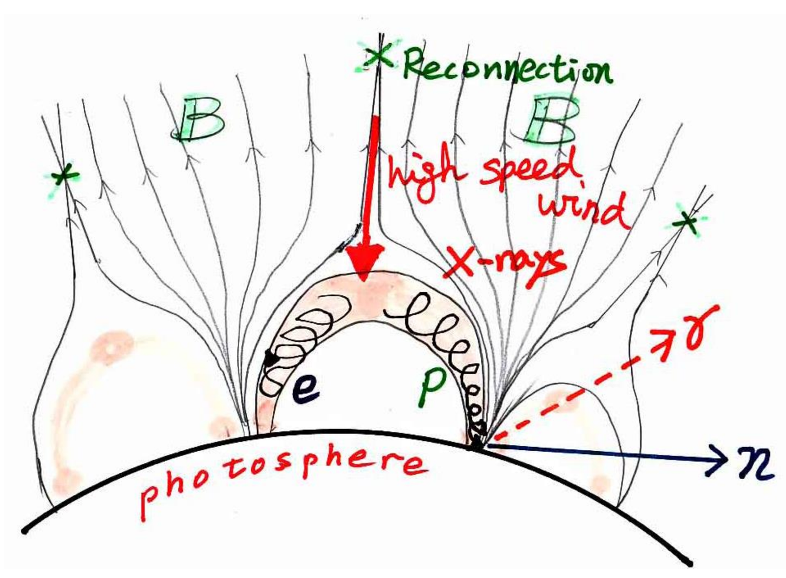

Fig. 2. The production of neutrons during solar flares [5]

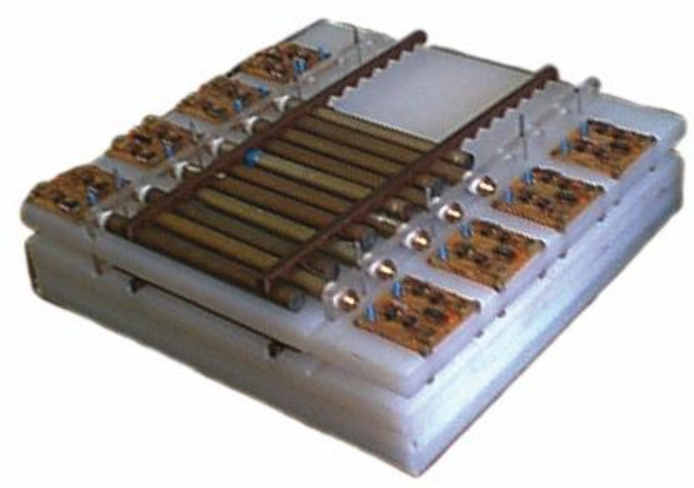

Fig. 3. The PAMELA neutron detector

Data analysis and results. To reduce the overflow effect, it was developed a method based on an additional analysis of the neutron count rate dependence on latitude for different time intervals. Using this dependence the minimum values of the background channel indications were determined depending on the time interval of the measurements. This allowed to correct the data in those cases when due to memory cleaning after its overflow the value of the neutron counter was distorted. The correction was made for each of the planes of the neutron detector since their count rates were slightly different. After the introduction of this correction the linear dependence of the counter readings on the duration of the measurement interval was enlarged up to 100 ms. It is much higher than the average value (30 ms). This allowed us to use time intervals larger than before for determining the neutron count rates and thus to reduce the fluctuations in the count rates. After this correction the statistical fluctuations of the neutron count rates decreased by a factor of ~ 1.5 and now do not exceed 1–2%. This is quite enough to separate the effect of solar neutrons at a few percent from background.

The method of estimating the background consisted in determining the dependence of the average count rate on the rigidity of the geomagnetic cut off (as in Fig. 4) for a few days preceding the flare. Based on this dependence the expected count rate was determined. Figure 5 shows the event on January 6, 2014 as an example. As neutrons don't possess any electric charge the trajectories of their movement aren't influenced by magnetic fields. They travel from the zone of generation to the place of registration in the vicinity of Earth along a straight line unlike charged particles which have curved trajectory, "wrapping" over power lines of the Sun magnetic field passing longer way in comparison with neutron one. The registration of solar neutrons is possible in the interval from the estimated time of the onset of the flare-the appearance of X-rays (t = 8:00 + 8 min) before the increase in the count rate associated with the arrival of solar protons (8-40 minutes).

Table 1 provides a list of the events examined. The characteristics of these events were taken from the GOES data [6]. The possible time of observation of solar neutrons during flares was determined from the position of the satellite in orbit.

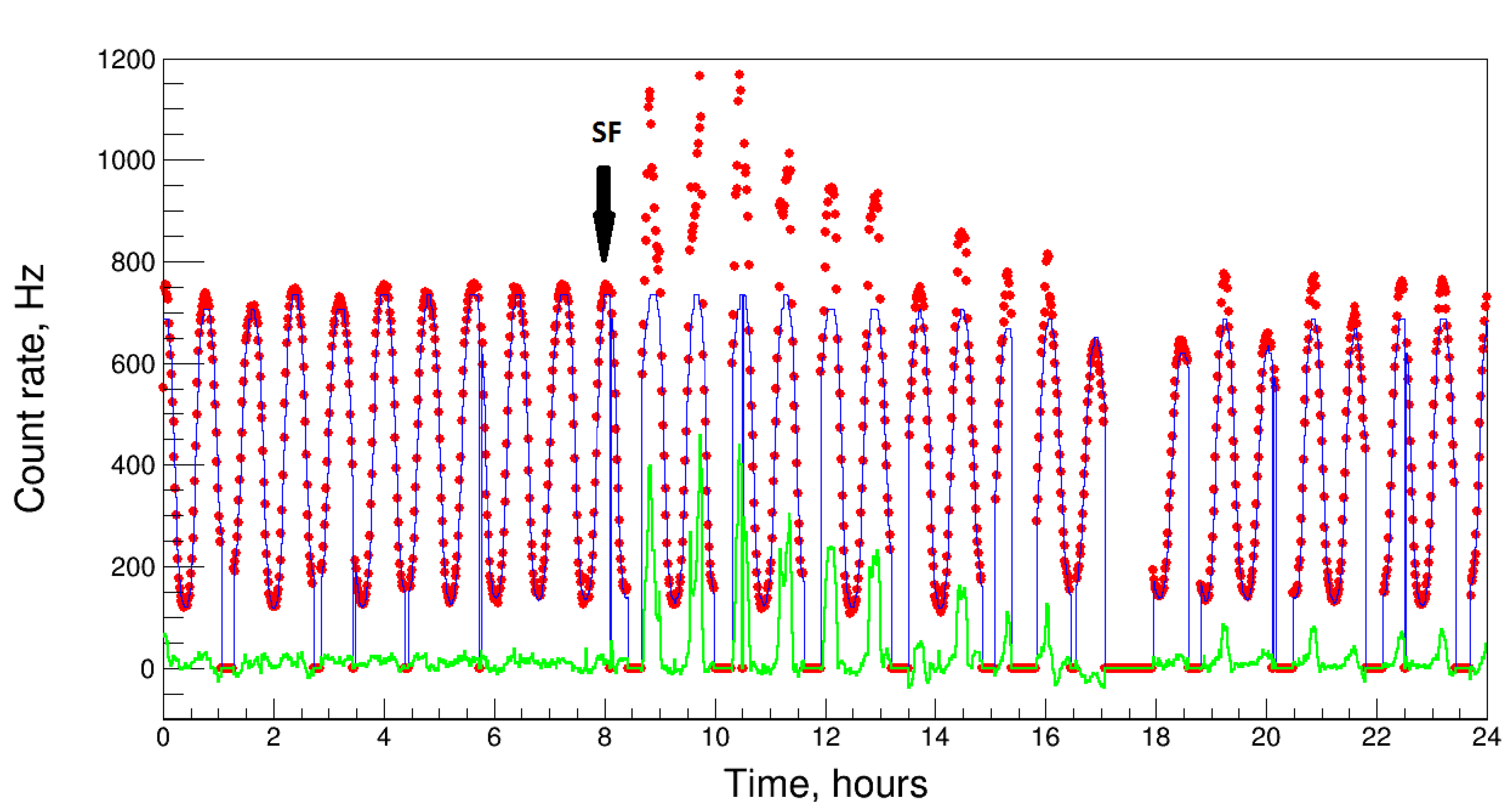

Fig. 5. Neutron count rate. SF is the time of solar flare beginning (08:00 UT). The blue curve is the expected cosmic ray albedo background count rate according to data for a few days before the solar flare. The red points are the measured count rate of 6 January 2014. The green line is the result after background subtraction.

At a high count rate the neutron detector memory overflows are possible. In [4] in order to reduce the overflow effect only the time intervals for neutron detection not exceeding 15 ms were considered (with an average duration of these intervals of 30 ms). Figure 4 shows the dependence of the count rate of the neutron detector on the rigidity of the geomagnetic cut off R for different selection criteria. The selection was carried out over time intervals ΔT between events. If ΔT is small, it is possible to avoid overflow of the counter memory. The L-coordinate is related to the rigidity of the geomagnetic cut off by the ratio: $R = 14.9/L^2$. Figure 4 shows that saturation can be avoided even at ΔT < 15 ms. This method was used to analyze solar events in 2006 – 2015 during solar flares when neutrons could be generated. And some indications were obtained for the registration of solar origin particles [4]. This approach allowed to avoid mistakes related to memory overflow but in the same time the statistical supply of results was significantly reduced.

In this paper we propose a new approach for solar neutrons searching.

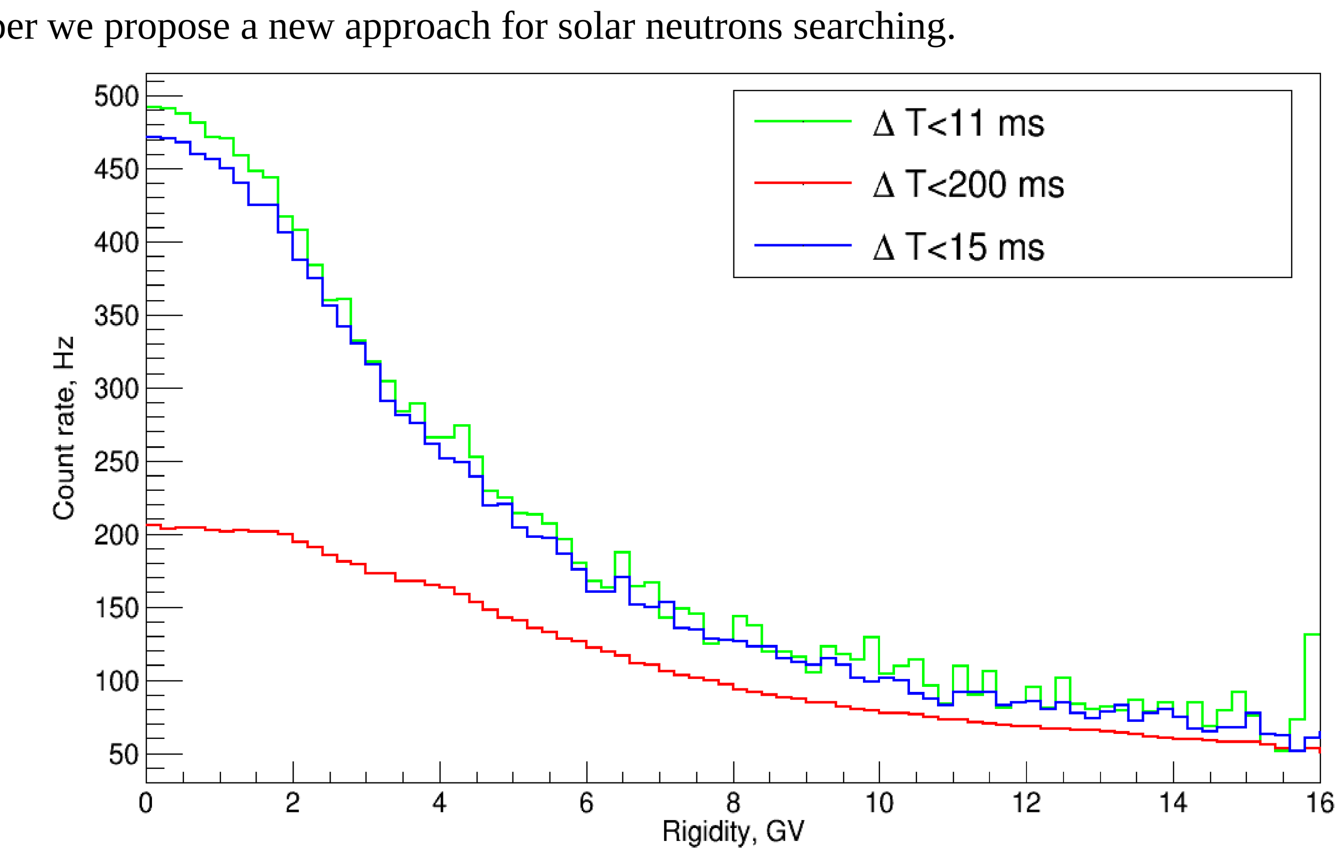

Fig. 4. Dependence of the neutron count rate on the rigidity of the geomagnetic cut off R for different criteria for the selection of events. The green curve is the time interval between events ΔT <11 ms, the red curve is ΔT <200 ms, the blue curve is ΔT <15 ms.

Table 1. Analysis of solar flares

Date	Flare class	The start time of the flare	The possible time of observation
06 December 2006	X9.0	10:35	11:14 – 11:15
13 December 2006	X3.4	02:40	03:07 – 03:20
14 December 2006	X1.5	22:15	22:23 – 22:25
06 September 2011	X2.1	22:20	22:28 – 23:00
08 September 2011	M6.7	15:46	16:08 – 16:26
03 November 2011	X1.9	20:27	20:35 – 20:56
07 March 2011	M3.7	20:12	20:20 – 20:52
07 June 2011	M2.5	06:16	06:24 – 06:56
23 January 2012	M8.7	03:38	03:46 – 04:18
27 January 2012	X1.7	17:37	17:59 – 18:17
05 March 2012	X1.1	04:05	04:13 – 04:15
07 March 2012	X5.4	00:24	00:32 – 01:04
09 March 2012	M6.3	03:45	03:53 – 04:23
13 March 2012	M7.8	17:25	17:47 – 18:05
17 May 2012	M5.1	01:47	01:55 – 2:20
06 July 2012	X1.1	23:01	23:17 – 23:41
19 July 2012	M7.7	04:17	04:30 – 04:57
11 April 2013	M6.5	06:55	07:06 – 07:35
12 April 2013	M3.3	20:38	20:46 – 20:57
22 May 2013	M5.0	13:08	13:16 – 13:48
06 January 2014	–	08:00	08:08 – 08:40
07 January 2014	X1.2	18:04	18:12 – 18:44
01 September 2014	C1.6	18:03	18:11 – 18:46
20 February 2014	M3.0	07:56	08:04 – 08:15
08 July 2014	M6.5	16:20	16:28 – 16:29
29 March 2014	X1.0	17:48	17:56 – 18:82
18 April 2014	M7.3	13:03	13:11 – 13:43

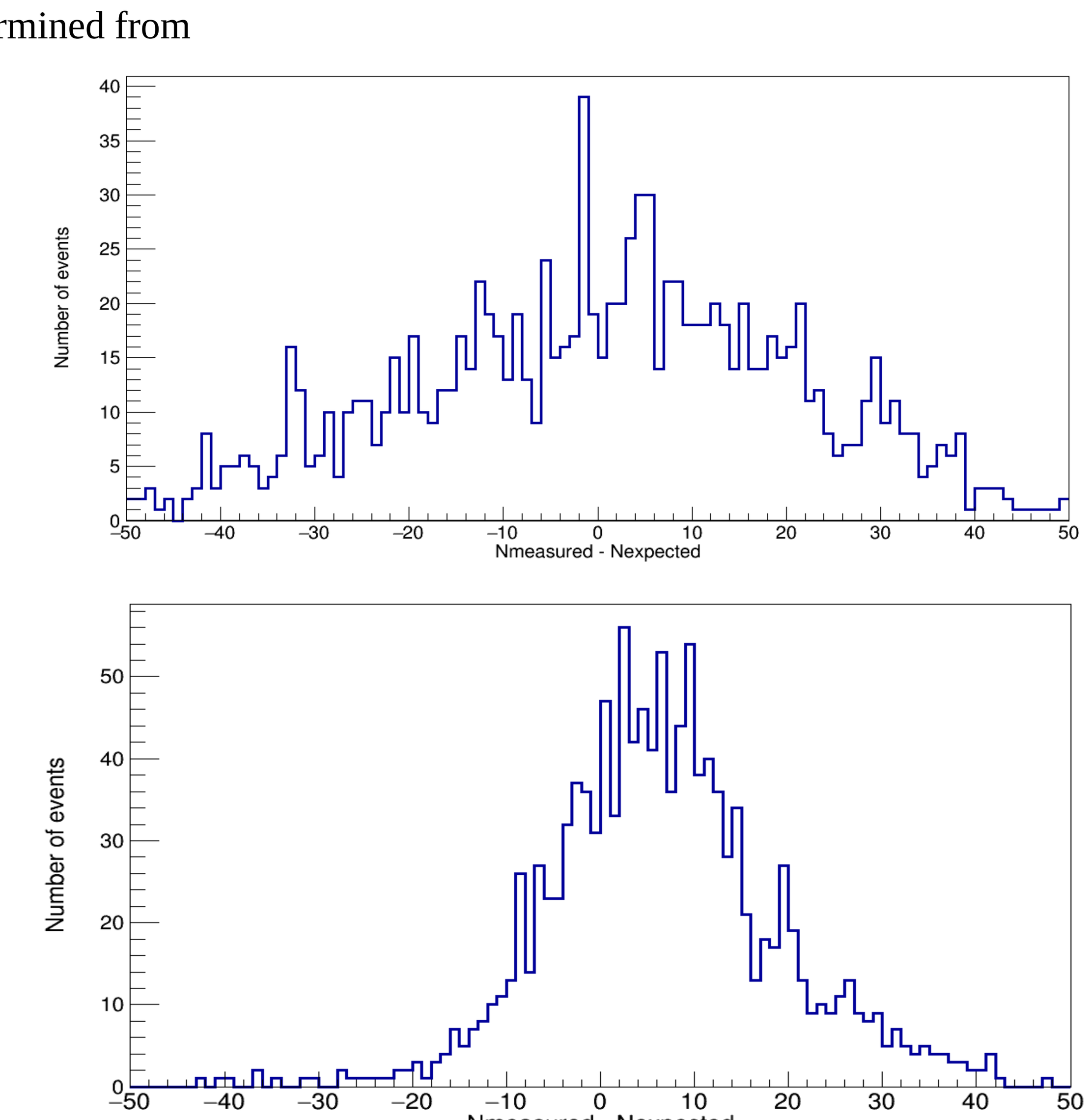

Fig. 6. The difference between the expected and measured count rates before and after the correction for 31 August 2014 (without solar flare). The upper figure: before the correction, the lower one: after it.

Conclusion. The analysis of 27 solar events from December 2006 to September 2014 in which neutrons could be generated was carried out. A noticeable excess (> 2%) over the background channel count rate of the neutron detector was not detected.

References

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