#### **OPEN ACCESS**

# Observing of atmospheric hadronic shower on the Barentsburg neutron monitor

To cite this article: Yu V Balabin et al 2013 J. Phys.: Conf. Ser. 409 012053

View the article online for updates and enhancements.

### You may also like

- Evidence of Energy and Charge Sign Dependence of the Recovery Time for the 2006 December Forbush Event Measured by the PAMELA Experiment R. Munini, M. Boezio, A. Bruno et al.
- <u>Electronic configurable neutron monitor for</u> <u>studying of atmospheric shower</u> Yu.V. Balabin
- <u>Letter of intent for KM3NeT 2.0</u> S Adrián-Martínez, M Ageron, F Aharonian et al.





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 52.15.210.12 on 21/05/2024 at 18:22

## **Observing of atmospheric hadronic shower on the Barentsburg neutron monitor**

#### Yu V Balabin, A V Germanenko, E V Vashenyuk, B B Gvozdevsky

Polar Geophysical Institute of RAS, 26A Akademgorodok, Apatity, Russia, 184209

E-mail: balabin@pgia.ru

Abstract. The neutron monitor in Barentsburg is equipped with a modernized data acquisition system which allows registering time intervals between pulses with 1  $\mu$ s accuracy. This high resolution makes it possible to study such fast and transient phenomenon like multiplicity. A multiplicity event is an isolated sequence of pulses with short time intervals between them. The Barentsburg neutron monitor consists of three sections, which are spaced at 5 m. In the present work a two-section multiplicity was studied, i.e. multiplicity events which are formed by pulses of two sections. We have assigned that each section must input no less than 4 pulses into an event to have a two-section multiplicity. The probability of a random coincidence of single pulses in this case is around 10<sup>-8</sup> (one event per ~10 days). But the real number of such events is ~10 per day. The other characteristics of two-section multiplicity. So this is undoubtedly real multiplicity. We consider it to be an effect of atmospheric hadronic shower on the NM. The cross-section size of such shower is estimated about 10 m according to the distance between sections.

#### **1. Introduction**

The neutron monitor 18-NM-64 in Barentsburg (78.06°N, 14.22°E, Spitsbergen archipelago) consists of three sections 6-NM-64. The sections are located in separate lodges within ~5 m of each other (Fig.1). Since 2006 the neutron monitor (NM) is equipped with an advanced data acquisition system. The system registers each pulse: which counting tube produced the pulse and the time elapsed after the previous pulse. Time intervals are measured with 1  $\mu$ s accuracy. The average count rate of the NM is

about 100 pulses per second, hence the average time interval between pulses is about 10 ms. But occasionally a sequence of pulses with very short intervals occurs. Such event is called a multiplicity. Time intervals inside a multiplicity are of order 10-100  $\mu$ s. We consider an event as a multiplicity if intervals do not exceed 500  $\mu$ s. Hereafter we will say 'multiplicity M' if the multiplicity contains M pulses.

On the basis of a huge data array collected for several years we have studied multiplicities with numbers  $M=5\div70$ . There are some additional conditions in determining of multiplicity. Those conditions and their substantiation as well as the



Figure 1. General view of the three sections of Barentsburg neutron monitor.

detailed description of the data acquisition system are given in [1-4]. The results of detailed studies of multiplicity events are represented in [3]. Here we mention them briefly:

- For each value of M average temporal profiles have been obtained (Figure 2). It was shown, that for M>10 there are two distinctive phases in profiles: main and relaxation. On the main phase of a multiplicity the average interval between pulses  $\Delta t$  is 30-50 µs for any M. On the relaxation phase  $\Delta t$  monotonically grows up to 200 µs. The length of a relaxation phase is the same for any M involving last 8-9 intervals.
- On the range M=5÷70 the spectrum of multiplicities was found. It is well approximated by a power law with an index -4.
- The average duration of events is defined for various M.
- The spatial distribution of pulses in various multiplicities has been studied. Small multiplicities (M<10) are generally formed by pulses from 2-3 contiguous tubes only (a transversal size ~1 m). Multiplicities M>30 are distributed on all tubes evenly (a transversal size > 3 m).

Our conclusion was that the large multiplicities are produced by local hadronic showers in the



**Figure 2.** Average profiles of multiplicities M = 7, 20 and 35. On the profiles M20 and M35 the profile M7 is superimposed and shifted to ends to show that relaxation parts of profiles are the same.

#### 2. Two section multiplicity

are produced by local hadronic showers in the atmosphere above NM [3]. The life-time of a shower gives a main phase of a multiplicity. During this phase the neutron density into NM is constant (average intervals between pulses are the same). It should be noted that NM is sensitive to hadrons with energies more than 50 MeV [5]. Clouds of thermal neutrons, which live many milliseconds and spread widely [6], have no effect on NM. The relaxation phase occurs after a shower and is a dispersion of neutrons or their absorption by tubes.

In our previous studies only one section data were used. The task of the present work is to find and investigate the multiplicities composed of pulses from different sections. The presence of such events would undoubtedly confirm the existence of local hadronic showers. There is a negligible probability for neutrons to be produced in one section and to be registered in another one.

First of all, the probability of accidental coincidences must be estimated. In paper [1] the probability to form a multiplicity event M=5 by 5 background accidental coincident pulses is calculated. It is  $\sim 5 \cdot 10^{-9}$ , that means one event per 20 days. It is clear that the probability of appearance of such event simultaneously in two sections is insignificant. Multiplicity events come accidentally and have a Poisson distribution:  $(nt)^k = nt$ 

$$p_k = \frac{(nt)^k}{k!} e^{-nt} \tag{1}$$

where  $p_k$  is a probability of k events occurring in an interval of time t if these events occur with an average rate n. Let's estimate the probability of appearing of two (k=2) independent events M=5 in different sections during t=2 ms (Duration of one event ~600 µs; a pair of events M=5 forms an event M=10 if the interval between them does not exceed 500 µs (see conditions of multiplicity detection in [1]). So the maximum duration of such composite event is ~2 ms). Actual number of events M=5 in NM is 1 per 10 seconds (n=0.1). Having substituted these parameters in (1), we obtain the probability  $2 \cdot 10^{-8}$ . I.e. one such event per a week. While data show, that such events (5 pulses in one section and 5 in another within one multiplicity) are observed about tens times per a day. The probability of an accidental coincidence of multiplicities M>5 is much less, since their number decreases like ~M<sup>-4</sup>. For

events with M<4 the probability of an accidental coincidence is not so negligible. So we selected and investigated multiplicity events with M $\geq$ 4. Other conditions for searching of multiplicity events remain as in [1].

Figure 3 shows some characteristics of the two-section multiplicity averaged over two years (2010-2011) data of Barentsburg NM. All multiplicity events without exception were taken for averaging for given M. Sections 1 and 3 data were used. The distance between the sections is more than 10 m. The spectrum represented in Fig.3a is normalized per day. Average time profiles of multiplicity events M=20 and 50 are shown in Fig.3b. Their form insignificantly differs from multiplicity profiles in one section (see Fig. 2). Both the main and relaxation phases can be clear discerned as well. A time profile of multiplicity M is calculated as follows. The first intervals (time duration between the first and second pulses) of all multiplicity M events are summarized and average value is computed. This is the first point of the time profile. The second point of the time profile is computed in the same way between second and third pulses and so on.

Constancy of the intervals between pulses in a main phase in figure 3b means, during this phase pulses follow one after another at small and equal intervals. While during a relaxation phase monotonic growth of intervals between pulses is observed, i.e. the multiplicity is really finished.



**Figure 3.** Characteristics of events of multiplicities, determined on two sections. **a**) The spectrum of multiplicities normalized per a day. **b**) Average profiles of multiplicities M=20 and 50.

The average durations of events of each value M have been calculated also. These values differ insignificantly from those in one-section multiplicity events. Detailed study of each event shows that a two-section multiplicity event is not just a sequence of two different one-section events. Pulses from different tubes of the two sections are distributed almost homogeneously during an event. This indicates the presence of a single source generating a multiplicity event in two sections simultaneously. Similar temporal profiles of one- and two-section multiplicities confirm that there is no difference between them.

Actually there is a difference in a spatial distribution. Multiplicities with small M (M <  $\sim$ 10) in one section, studied earlier [1, 3], consist of pulses from 2-3 adjacent tubes only. As for two-section multiplicity, even at small values of M the pulses are distributed almost evenly on all counters.

Here is one more interesting result. We asked ourselves, do pulses within a multiplicity appear occasionally and independently or there is some "coherence"? Due to recording of detailed information about each multiplicity event it is possible to answer. Selecting events with M=13 to construct an averaged temporal profile (like in Fig.3b), we added additional conditions. Firstly the condition was "The 11<sup>th</sup> interval must be less than 100  $\mu$ s" briefly "11<sup>th</sup> < 100", and the secondly "The third interval must be more than 100  $\mu$ s" briefly "3<sup>rd</sup> > 100". The total number of M=13 events is so huge that even under these additional conditions the averaged profile is statistically significant. The result is present in Figure 4. One can see that the first condition influences 11<sup>th</sup> interval solely: our condition "11<sup>th</sup> < 100" disturbs only 11<sup>th</sup> intervals, other intervals are averagely the same. The other



**Figure 4.** Profiles of multiplicity M=13. Blue curve - no additional condition. Green curve - condition "the  $11^{\text{th}}$  interval is less than 100 µs". Red curve - condition "the  $3^{\text{rd}}$ interval is more than 100 µs".

situation is under the condition " $3^{rd} > 100$ ". It influences not only the  $3^{rd}$  interval (pulse, neutron) but also a couple of intervals before and after it. This reveals some "coherence" of pulses (neutrons) at the main phase of multiplicity. During the relaxation phase a real independence is observed. This difference gives an evidence of the different nature of the phases. The relaxation phase comes after a local shower. Neutrons have forgotten their origin, they are scattered and rambles independently. In the main phase neutrons "remember" their origin from an initial energetic particle. So the condition " $3^{rd} > 100$ " means to exclude some wisp of neutrons within a shower, i.e. before and after the third particle.

The obtained results in addition confirm the conclusion made earlier [3], that multiplicities M>10 and especially M>30 are produced by local hadronic showers. In [3] on the basis of one section data the estimation of transversal sizes of such showers ~3-5 m was made. On the basis of new results it is possible to expand this estimation of sizes up to 10-15 m for M>50.

### **3.** Conclusions

We have studied the multiplicity events, consisting of pulses from two separated sections of a neutron monitor. The presence of such events proves the existence of local hadronic showers. The showers produce multiplicity events M>10. Large hadronic showers can cover two sections of NM and generate two-section multiplicity. There is a "coherence" of multiplicity neutrons. According a disposition of sections and the measured parameters of a multiplicity the new estimation of a transversal size of local hadronic showers is made. It is ~10-15 m in a case of events M>50.

### 4. References

- [1] Balabin Yu V, Gvozdevsky B B, Maurchev E A, Vashenyuk E V and Dzhappuev D D 2011 *Astrophys. Space Sci. Trans.* 7 283–286
- [2] Balabin Yu V, Dzhappuev D D, Gvozdevsky B B, Maurchev E A, Kudzhaev A U and Mikhailova O I 2011 Neutron Multiplicity: Local Hadronic Showers and Extensive Air Showers Bulletin of the Russian Academy of Sciences. Physics 75 364–366
- [3] Balabin Yu V, Gvozdevsky B B, Vashenyuk E V and Dzhappuev D D 2011 *Proc. of 32<sup>nd</sup> ICRC* (China, Beijing, 11–18 August 2011) ID 672
- [4] Balabin Yu V, Gvozdevsky B B, Vashenyuk E V and Schur L I 2008 Observing Multiplicity Effect during December 13, 2006 event on the Barentsburg Neutron Monitor *Proc. of 30<sup>th</sup> ICRC* (Mexico, Merida, 3-11 July 2007) 1 257-260
- [5] Dorman L I 1975 Exper. and Theor. Foundations of Space Rays Astrophys. (Moscow: Nauka)
- [6] Stenkin Yu V 2008 Nucl. Phys. B 326 175–176