Detection of low-energy muons in the stratosphere

Yu. A. Aleksandrov, V. G. Afanas'ev, K. G. Afanas'ev, E. V. Gorchakov, V. A. Iozenas, I. A. Rubinshtein, and Yu. I. Stozhkov

Nuclear Physics Research Institute, M. V. Lomonosov State University, Moscow; P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted 22 February 1990)
Zh. Eksp. Teor. Fiz. **98**, 387–389 (August 1990)

We concisely describe the characteristics of a device designed to detect 25–80 MeV muons. The detector is a cylindrical thallium-doped NaI crystal 8 cm in diameter and 8 cm long. We present calculated values of the geometry factor for muons of various energies and for particles that are not stopped by the detector. The geometry factor for muons at energies below 55 MeV is, on average, 2.5×10^{-2} $m^2\cdot sr$, and it drops to zero above 80 MeV. We describe stratospheric measurements up to 28 km at 67.5° latitude. The problem of spurious coincidences contributing to the overall detected muon flux is discussed. The muon differential energy spectrum rises with energy. The intensity of 30-MeV muons is $(5\pm 4)\times 10^{-2}(m^2\cdot sec\cdot sr\cdot MeV)^{-1}$, increasing to $0.25\pm 0.12(m^2\cdot sec\cdot sr\cdot MeV)^{-1}$ at 70 MeV. Our results provide information about the muon flux in a hitherto unexplored energy range.

Interest in fluxes of slow muons in the stratosphere has been on the rise of late. Information about the energy spectrum of muons at altitudes of 10–30 km eases the task of explaining temporal variations in the neutrino fluxes observed on earth. Thus, far, experiments in the stratosphere have been designed to examine muons with energies above 100 MeV.[1,2] According to Tulinov,[1] the flux of 100-MeV muons at 51 °N is $\sim 1.7(m^2\cdot sec\cdot sr\cdot MeV)^{-1}$.

To study muons at energies above 100 MeV, we constructed an instrument designed to fly on a high-altitude balloon. The detector is a cylindrical crystal of NaI(Tl) 8 cm in diameter and 8 cm long that is optically coupled to a photomultiplier. The muon selection signal enabling us to discriminate against background particles is the pulse due to the decay electron. The signal-processing electronics following the detector enables us to measure the time between two successive events, and to perform a pulse-height analysis on the detected signals (using a 24-channel analyzer). The time delay to the electron-decay pulse is measured to a precision of 100 nsec over the range 0.5–12.8 μsec (the amplitude of that pulse is not measured). The pulse-measurement accuracy is 5%. The energy deposited in the crystal can be measured over the range 25–80 MeV. The processing electronics also contains a counter for the total number N of pulses exceeding some amplitude threshold.

The instrument has operating modes that enable it to determine the spectrum of the energy absorbed both from muons brought to rest in the detector and from particles that are detected without an accompanying delayed pulse (we call the latter penetrating particles). Measurement of the spectrum of the penetrating component is of interest in its own right, but in addition, one can only obtain reliable information on the low-energy muon flux if the shape of that spectrum is understood, the reason being that in analyzing events satisfying the detection criteria for muons brought to rest in the detector, it is also necessary to allow for spurious coincidences. In fact, it can easily be shown that in monitoring pulses occurring at some rate n, the probability that two pulses will be detected within some time interval τ is $n^2\tau$. To take this accurately into account, the overall count rate in each channel of the pulse-height analyzer must be known. We shall describe the procedure for subtracting spurious events below.

With regard to the detection efficiency for muons stopped by the detector, an understanding of the muon-energy dependence of the efficiency requires that one reckon with the following factors:

a) the probability distribution for particles traversing a particular path through the detector depends on their energy and on the angular distribution of incident particles;

b) electrons produced by μ-e decay have a definite energy spectrum, which peaks at 37 MeV (Ref. 3). Some fraction of the electrons will then have an energy below the detection threshold of the electronics;

c) decay electrons are distributed isotropically, and some fraction of them, even those with enough energy, may fail to trigger the detection circuitry because they fall outside the detector's angular acceptance limits;

d) the electronics cannot respond to muons that decay in less than 500 nsec. This can easily be shown to require a 25% correction to the geometry factor.

A Monte Carlo calculation of the geometry factor, simulating an isotropic muon flux incident upon the cylindrical detector, yielded a detection threshold of 25 MeV. The fraction of electrons below threshold was taken to be 20%. The

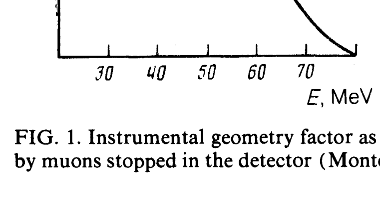

FIG. 1. Instrumental geometry factor as a function of energy deposition by muons stopped in the detector (Monte Carlo calculation).

 0038-5646/90/080217-02$03.00

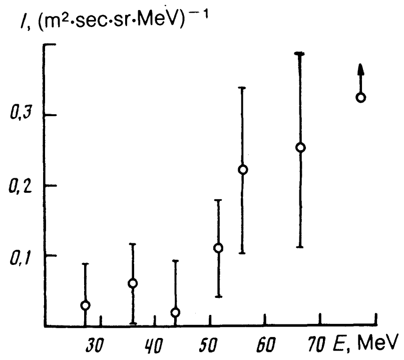

FIG. 2. Muon energy spectrum recorded on 30 January 1986 from a balloon at approximately 28 km altitude. The flight was launched from Apatity (67.5 °N), with the geomagnetic cutoff at 0.6 GV.

calculated dependence of the geometry factor on energy deposited by muons stopped in the detector has been plotted in Fig. 1.

An experiment was conducted on 30 January 1986 in the city of Apatity (67.5 °N). The total exposure time was 2.5 h. The balloon ascent phase took approximately 1.5 h, following which the instrument spent 1 h at an altitude of 28 km. The total-event counter on board, which registered a count rate of approximately 1.1 counts per second at sea level, measured a maximum of 190 counts per second at about 18 km, which then fell off to 170 counts per second at 28 km for the remainder of the experiment. In all, more than 6×10^5 pulses above threshold were recorded above 18 km. During that exposure period, the total number of events satisfying the detection criteria for stopped muons was 950.

To construct the low-energy muon spectrum, we made use of the pulse-height distributions both for particles satisfying the stopped-muon criteria (with the adopted value of τ being three times the muon lifetime, i.e., $\tau = 7\ \mu$sec) and for penetrating particles (i.e., particles accompanied by a second pulse more than 7 μsec later). As we remarked above, the former distribution does not accurately reflect the energy spectrum of the muons in question, since it includes a contribution from spurious coincidence events that is actually quite large. In fact, during the time spent at maximum altitude, the average in each of the instrument's pulse-height channels was approximately 2×10^4 events due to penetrating particles. In other words, the mean count rate n_i in the ith channel was 7.5 counts per second, while during the same period the total rate over all channels was an average of 170 counts per second. The number of false alarms expected in one channel in a time interval τ is $Nn_i\tau$. In the present case, that means that an average of 30 false alarms will be recorded for each legitimate muon detection, or approximately 75% of all events in a given channel.

Thus, in order to reconstruct the energy spectrum of the desired muons, it is necessary to transform the amplitude distribution of the energy deposited by the penetrating radiation into an expected false-alarm distribution for each channel, and then subtract the resulting values from the distribution for particles satisfying the muon detection criteria. The final transformation to intensity then employs the curve shown in Fig. 1.

The energy spectrum obtained in this manner is shown in Fig. 2. In plotting the calculated intensity, we have assumed that the radiation under investigation is distributed over a solid angle of 2π. Note that a sea level, the count rate due to muons in the 25–80 MeV range was 8×10^{-4} sec^{-1}, and it increased to 7×10^{-2} sec^{-1} in the upper layers of the atmosphere.

These results provide information on the muon flux in a hitherto unexplored energy range.

[1]V. F. Tulinov, Zh. Eksp. Teor. Fiz. **33**, 1167 (1957).
[2]A. N. Charakhch'yan and T. N. Charakhch'yan, Trudy Fiz. Inst. Akad. Nauk SSSR **64**, 3 (1973).
[3]A. D. Vaisenberg, *Muons*, North-Holland, Amsterdam (1967).

Translated by Marc Damashek