МОСКОВСКИЙ
ОРДЕНА ТРУДОВОГО
КРАСНОГО ЗНАМЕНИ
ИНЖЕНЕРНО-
ФИЗИЧЕСКИЙ ИНСТИТУТ

V. V. Borog A. Yu. Burinskij
O. M. Chugunova V. V. Dronov

028-93

LARGE APERTURE MUON HODOSCOPE FOR RESEARCH OF SOLAR-TERRESTRIAL PHYSICS (TEMP)

Moscow 1993

STATE COMMITTEE OF THE RUSSIAN FEDERATION
IN HIGH EDUCATION

MOSCOW ENGINEERING PHYSICS INSTITUTE

V.V.Borog A.Yu.Burinskij
O.M.Chugunova V.V.Dronov

LARGE APERTURE MUON HODOSCOPE FOR RESEARCH OF SOLAR - TERRESTRIAL PHYSICS (TEMP)

PREPRINT 028 - 93

Approved by the
editorial board of the Institute

Moscow 1993

УДК 524.I + 539.I.074.6

Borog V.V., Burinskij A.Yu., Chugunova O.M., Dronov V.V. Large aperture muon hodoscope for research of solar - terrestrial physics. - Moscow: Preprint / MEPhI, 028 - 93, 1993. - 12 p.

The 512-channel large aperture muon hodoscope has been developed to investigate the solar-terrestrial physics in the energy region above 10 GeV. The accuracy of the registration of cosmic rays direction is about 1-2 degrees in the solid angle close to 2π. The apparatus is on-line with the micro-computer. The counting rate is about 10^3 events per second.

The experimental setup is located at the ground level and is capable of being oriented in the Sun's direction. The 64-channel prototype of muon hodoscope has been tested. The obtained results demonstrated its working abilities. At the present time the construction of the full scale muon hodoscope is in progress.

ISBN 5 - 7262 - 0121 - 3

INTRODUCTION

The neutron monitors and muon telescopes have comparatively low angular resolution which does not allow to detect the direction of cosmic rays with a sufficient accuracy.

We describe the setup to investigate the solar-terrestrial physics in the energy region above 10 GeV including solar proton events, high energy flares, interplanetary magnetic field processes, local anysotropy and galactic point sources.

1. PHYSICS GOALS

1. Solar high energy proton events

The theoretical models of acceleration of particles coming from the Sun predict the possibility of existence of protons with energies up to 10^2 - 10^3 GeV [1].

The good angular resolution of this hodoscope (about 5×10^{-4} sr) allows one to suppress the background by a factor of more than 100 in comparison with the existing muon telescopes. The muons are detected within the range of zenith angles $0^\circ < \vartheta < 90^\circ$. The effective thickness of the atmosphere is changing from 10 to 300 m.w.e. The Table presents the energy characteristics of muons and protons at the different zenith angles.

For example, if the flare duration is 100 seconds then we can register the flux of high energy protons up to 10^{-6} - 10^{-7} cm^{-2} s^{-1} in angular region $0^\circ < \vartheta < 90^\circ$.

2. Mechanisms of high energy flares

The up-to-date models of solar proton events predict that the process of acceleration of high energy protons takes a short time: ≤ 10 - 10^3 seconds [2].

The time resolution of the hodoscope is about 10^{-7} seconds, which allows one to measure the time profile of the pulse of the accelerated protons.

This muon hodoscope is also capable of direct neutron detection ($E_n > 10$ GeV), produced in nuclear reactions at proton acceleration. Such neutrons have to move along the line between the Sun and the Earth. The secondary muons will also be moving in this direction.

Table

Zenith angle	ϑ°	0	45	60	70	85
Effective thickness of atmosphere	(m.w.e)	10	14	20	30	100
Energy of muons on the level of generation, GeV	E_μ^{min}	2 5	4.5	5.0	10.0	40.0
	$<E_\mu>$	8	14	16	34	120
Energy of protons, GeV	E_p^{min}	4	6	8	12	40
	$<E_p>$	20	30	40	60	200
Muon intensity (at sea - level) $cm^{-2}\ s^{-1}\ sr^{-1}$	$I_\mu, 10^{-2}$	0.9	0.7	0.2	0.09	0.01

3. Processes in the interplanetary magnetic field

Shock waves expansion. The intensity of galactic cosmic ray protons with energies $E_p \geq 10$ GeV may be modulated by shock wave front. The measurement of intensity of muons in different directions allows one to estimate this effect. If the front velocity is $\approx 10^3$ km/s then the modulation of the muon intensity will be moving with the velocity about 2° per hour.

The space inhomogeneity of interplanetary magnetic field. At quiet Sun the investigation of anysotropy of the muon intensity from the galactic cosmic rays in the different directions could give information about the dimensions of interplanetary magnetic field.

The estimates show that the maximum modulation due to the inhomogeneity with a size (0.1 - 1.0) a.u. concerns to the region of proton energy (5-50) GeV, that corresponds to the range of the muon hodoscope.

4. Cosmic ray interaction on the solar surface

Some estimates of the flux of neutrons and other particles that result from collisions of high - energy Calactic cosmic rays (≥ 100 GeV) with the solar atmosphere are available [3]. The neutron flux may appear detectable by means of our setup.

5. Geophysical effects

Internal gravity waves. The oscillations of atmospheric density lead to modulation of muon intensity registered at ground level. The sensibility of a setup to this process noticeably increases if one registers muons in different directions in a wide range of zenith angles. The muon hodoscope allows one to estimate the velocity, length, direction and amplitude of such waves.

Wave processes from the helioseismic. The wave oscillations of the solar magnetosphere may cause the modulation of galactic cosmic proton intensity in the Earth's direction. The good angular resolution of hodoscope provides an opportunity to carry out the observation of this phenomena. During one year of observations in the aperture $\delta\Omega = 10^{-4}$ sr about 3×10^6 muons from galactic protons may be registered at the total statistics of muons more than 10^{10}.

2. EXPERIMENTAL TECHNIQUES

1. Construction of the hodoscope

The detector includes 512 plastic scintillator counters. Each of the counters represents a narrow stripe; its length is 300 cm, cross-section is 2.5×1.0 cm^2. The photomultipliers coupled to each stripe provide the safe registration of relativistic muons. The diameter of the PMT input window is 25 mm. In the worst event, when a muon passes 3 meters away from PMT, it produces not less than 10 photoelectrons, which corresponds to 100 % efficiency of the counter [4].

The muon hodoscope is made of four layers. Each of the layers consists of 128 counters. The figure 1 shows the scheme of the hodoscope. The neighbouring layers X, Y form the coordinate axes. The distance between the two pairs of layers is about 1 meter. For the safe muon registration the lead filter (5 cm) is used. The fifth layer of scintillators (Z) is added for a master formation.

The passage of a muon through the all layers causes the signals in four coordinate detectors. This provides the reconstruction of the angles with the accuracy of about 1-2°. The aperture $\delta\Omega$ of the elementary cell is less than 5×10^{-4} sr.

2. The system of on-line data processing

The muon hodoscope has 128 x 4 independent channels. The read-out time of each event is 32 microseconds. In order to decrease the dead time the buffer rapid memory is used. As a result of on-line data processing the differences of coordinates ($\Delta X, \Delta Y$) are calculated to reconstruct the angular characteristics of muon trajectory. The rate of the information reception is about 10^4 words per second. The data are compressed in order to record on magnetic tape. The scheme of the registration system is shown in figure 2.

3. The off - line data processing

The useful information is 10^9 words per 24 hours. There is a necessity to provide the geometric reconstruction, correlation and Fourier analysis, which is related to the arithmetic calculations with double precision. Therefore a computer has to carry out not less than 10^5 of these operations per second.

At the present time the system of data processing is developed and its scheme is shown in figure 3a. The original information is prepared by micro-computer DVK-3M (LSI-11) in on-line regime and is recorded on the magnetic tape drive IZOT 5300.01.

For off-line data processing the information is passed in DVK-4M (PDP-11/34). The usage of this tape in a waiting regime is not reliable for the whole year of the experiment. The reliability of another registration system and data processing shown in figure 3b is much better. In this system the VAX computer with an optical disk is supposed to be used.

4. Prototype

The 64-channel prototype of the muon hodoscope has been made for testing and calibrating the registration system. The prototype consists of 4 layers of 16 scintillation counters. The axes of all counters are aligned in one direction. The distance between neighbouring layers is about 10 cm. Such a geometry provides the counting rate about 100 events/second in cosmic rays.

The time characteristics of the registration system have been measured. The figure 4 shows the dependence of registration efficiency on the trigger delay. The average value of this delay is 170 ns. The triggering time is about 70 ns.

The triggering efficiency of a separate layer (E_f) was tested on the prototype working in the regime of three-fold coincidences. The value of E_f is about 96%. The distribution of the triggering frequency of separate detectors in the four-fold regime has been measured. Figure 5 shows the distributions for each layer. Such a configuration of the registration system provides the on-line operation at the average counting rate up to 10^3 events per second with a good efficiency.

5. Technical characteristics of the muon hodoscope

1. Effective area - 9 m^2.
2. Angular resolution 1-2°.
3. Aperture of a separate cell $\delta\Omega = 5 \times 10^{-4}$ sr.
4. Solid angle Ω is close to 2π.
5. Range of zenith angles $0° < \vartheta \leq 90°$.
6. Counting rate $\simeq 10^3$ s^{-1}.
7. Resolution time $\simeq 10^{-7}$ s.
8. Arrival time accuracy $\simeq 10^{-5}$ s.
9. Registration efficiency $\geq 96\%$.
10. Accuracy of atmospheric pressure - 0.1 mm Hg.
11. Operation time - 24 hours/day (over all year).
12. Location depth - 2 m.w.e. (Moscow).
13. Cutoff rigidity - 2,4 GV.

ACKNOWLEDGMENTS

We wish to thank prof.A.A.Petrukhin for helpful discussions. This work was supported in part by the Russian Fundamental Research Foundation (grant 93-02-3061).

REFERENCES

1. Miroshnichenko L.I., Geomagnetizm i aeronomiya, v.32, N6, p.1 (1992).
2. Ellison D.C., Ramaty R., Astrophys.J., v.298, p.400 (1985).
3. Seckel D., Stanev T., Gaisser T.K., Astrophys.J., v.382, p.652 (1991).
4. Borog V.V. et al., Report MEPhI N87-3-19, (1990).

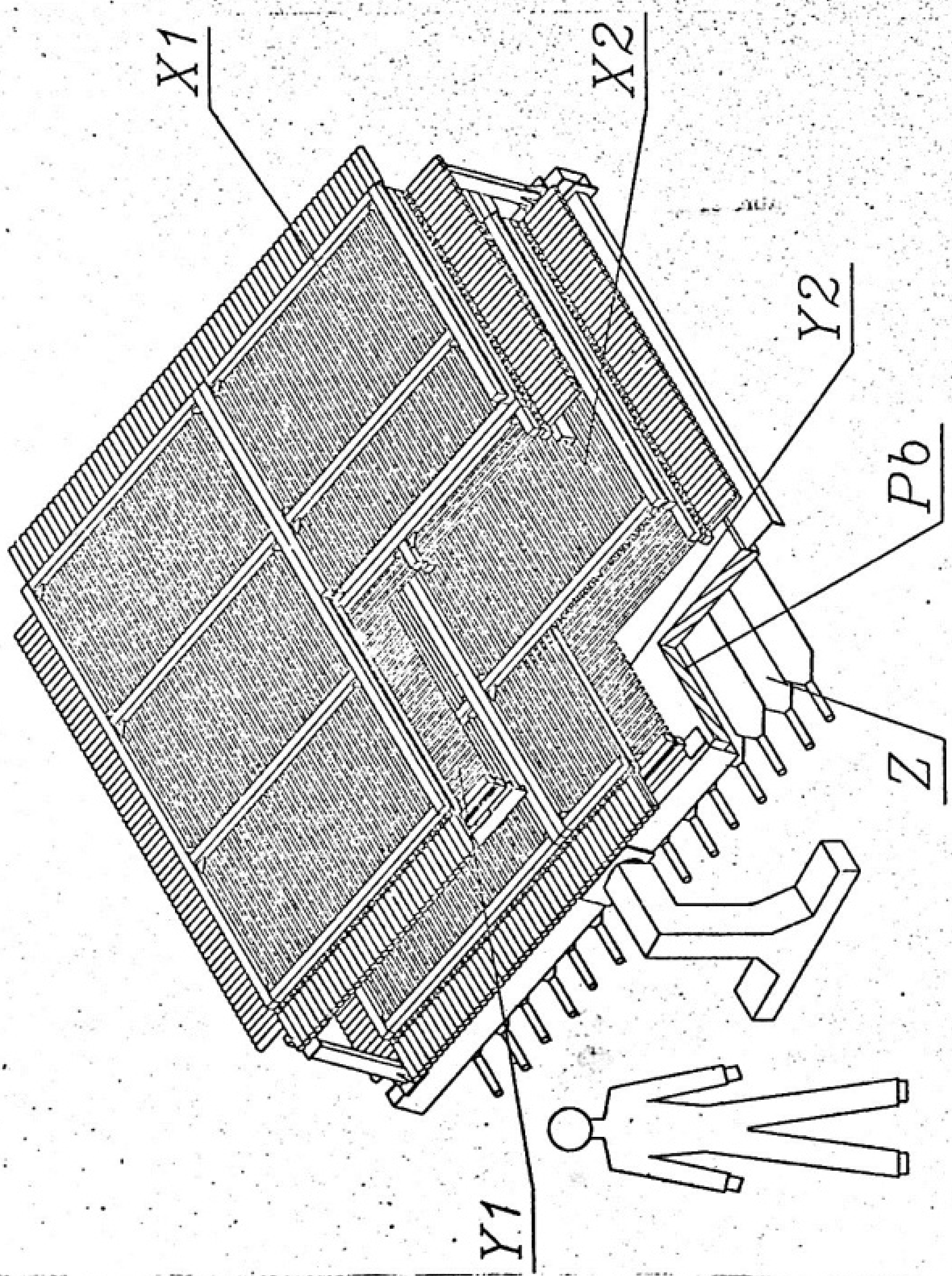

Fig.1. General view of the hodoscope (area 3∗ 3 m²). X1, Y1 - the upper (X2, Y2 - the lower) layers of scintillators (4 ∗ 128 - of counters). Z - the trigger layer. Pb - 5 cm lead absorber

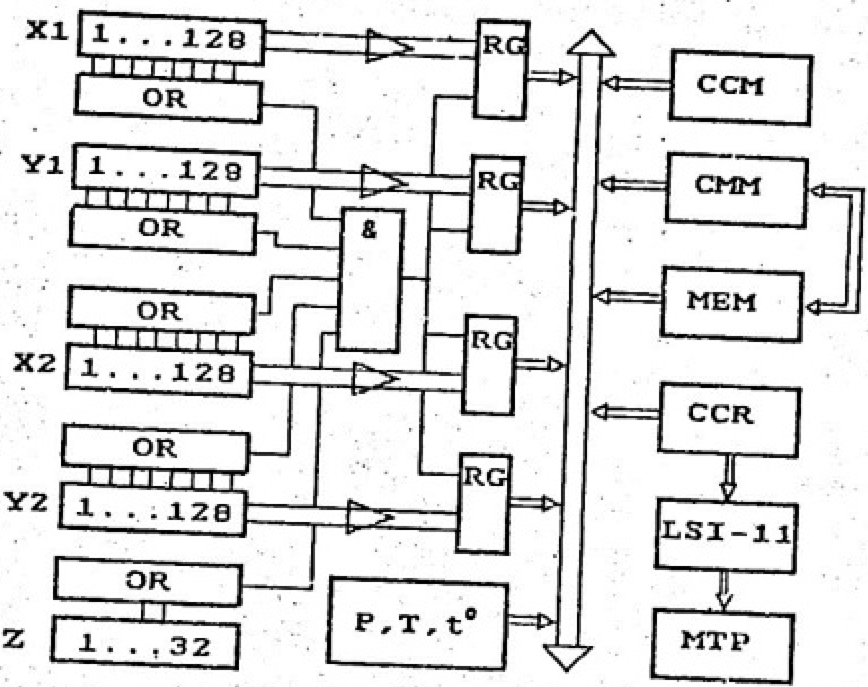

Fig.2. Block - diagram of the on-line counter experiment:
X1, Y1, X2, Y2, Z - the pulse-formers
LSI-11 - micro-computer (DVK-3M)
OR - the layers OR-s
& - five-fold coincidence circuit
RG - input registers
CCM - complementary controller of the fast memory
CMM - memory management controller
MEM - fast memory.
CCR - the CAMAC crate controller
MTP - magnetic tape drive

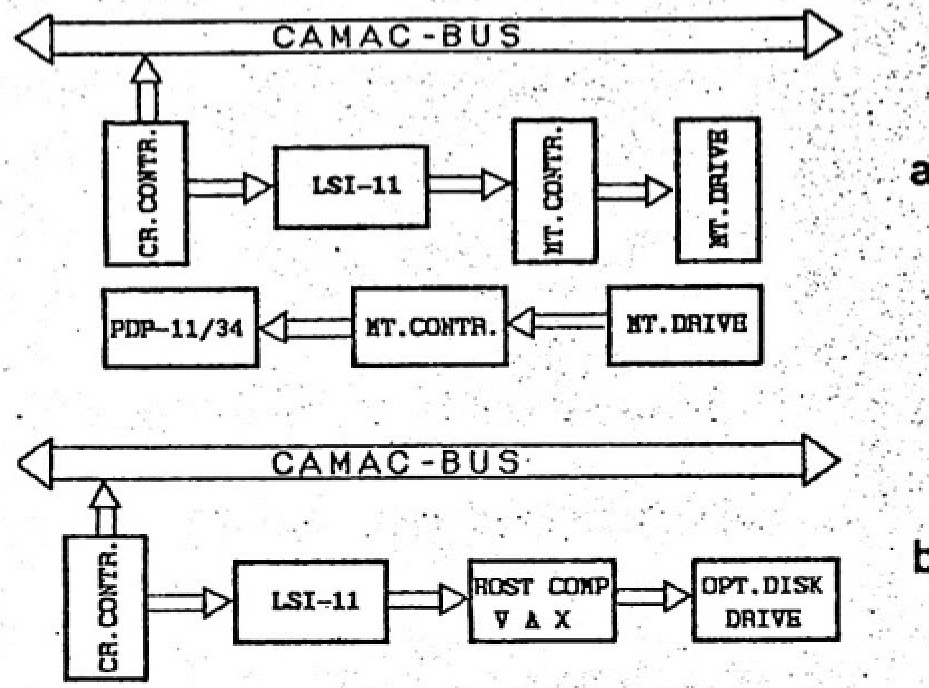

Fig.3. Block diagram on-line and of-line of the data processing;

a - the real sheme:

CR.CONTR	-	CAMAC crate-controller
LSI-11	-	micro-computer (DVK-3m)
MT.CONTR.	-	magnetic tape controller
MT.DRIVE	-	magnetic tape drive
PDP-11/34	-	mini-computer (DVK-4M)

b - the project:

CR.CONTR	-	CAMAC crate-controller
LSI-11	-	micro-computer (DVK-3M)
HOST COMP.	-	Host VAX computer
OPT.DISK	-	Optical disk (3-5 Gbt)

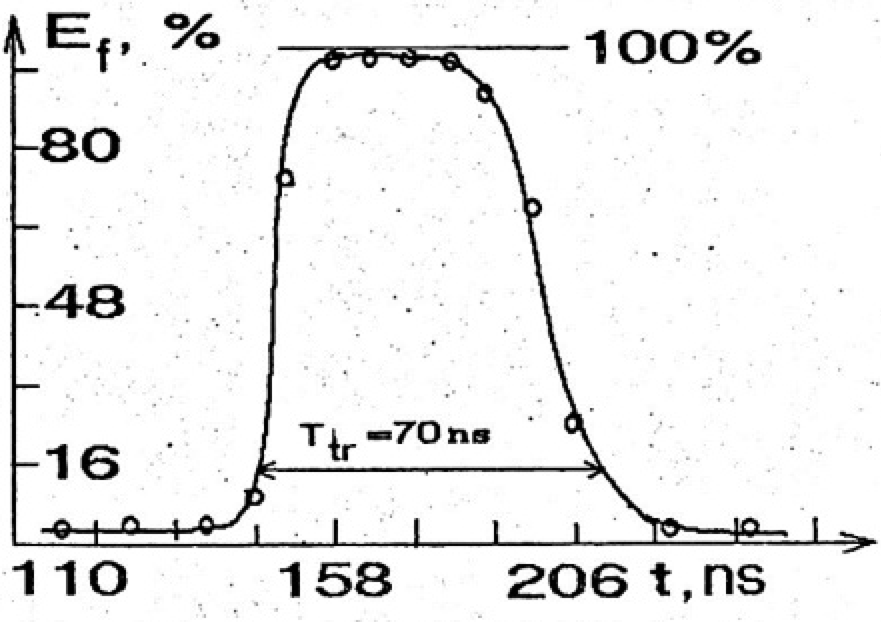

Fig.4. Dependence of registration efficiency on the trigger delay

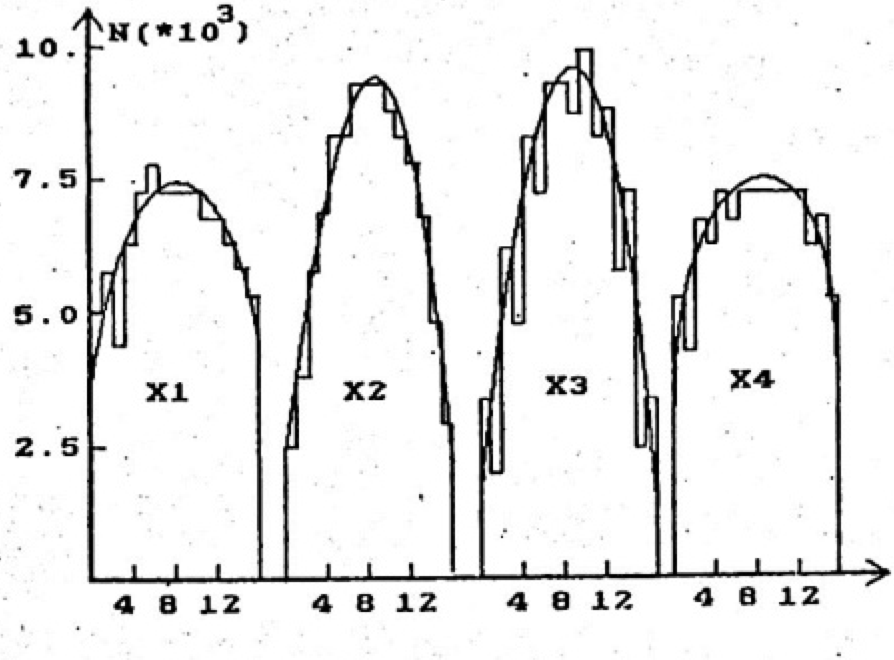

Fig.5. Measured coordinate distribution of triggering frequency of the separate counters on cosmic rays. X1, X2, X3, X4 - layers of coordinate counters in the hodoscope prototype

Рукопись поступила в редакционно-издательский отдел 07.12.93

Редактор М.В.Макарова

Лицензия ЛР № 020676 от 09.12.92 г.
Подписано в печать 22.12.93 г. Формат 60x84 1/16
Печ. л. 0,75 Уч.-изд. л. 0,75 Тираж 100 экз. Заказ 1056 Изд. № 028-93

Московский инженерно-физический институт.
Типография МИФИ, 115409, Москва, Каширское шоссе, 31.