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π^- STAR DETECTOR

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π^- STAR DETECTOR*

* *This detector has been described briefly in* [1].

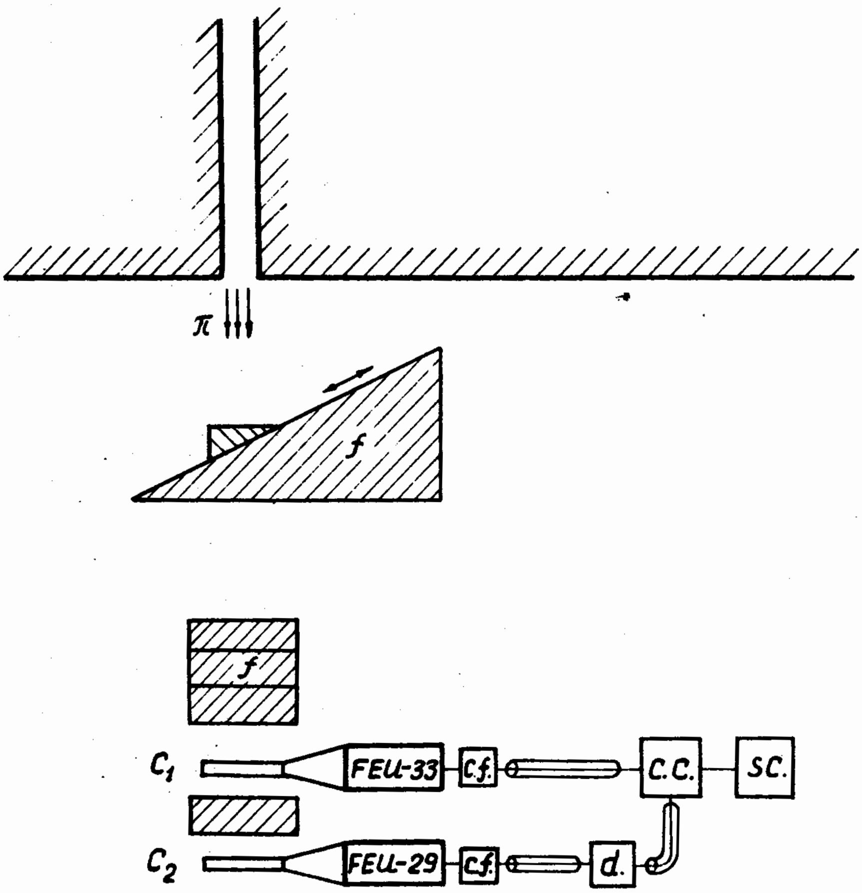
A scintillation detector possessing the selective sensitivity to π^- mesons is described. The detector records the stars due to π^- mesons coming to rest.

1. INTRODUCTION

Most of the π^- mesons stopping in matter give rise to stars-the nuclear disintegrations in which a considerable amount of energy is released, its magnitude being close to the pion mass (140 MeV). This feature makes π^- mesons distinct both from the light particles (μ mesons, electrons) which fail to produce high-energy stars, and from the positively charged nuclear-active particles (protons, π^+ mesons, etc) producing stars only in flight and with a small probability. By using the scintillator of the scintillation counter as a substance in which the particles are brought to rest, and by recording only the pulses produced by stars, i.e., those corresponding to a large energy release in the scintillator, it is possible to accomplish a simple detector which possesses a selective sensitivity to π^- mesons. A principle possibility of constructing such a π^- star detector, which is not sensitive to other particles, is not doubtful since the recording efficiency for particles which do not produce high-energy stars may be obtained whatever low by increasing the threshold for the pulse amplitude discrimination at the output of the scintillation counter. However, with increasing the discrimination threshold the efficiency of the star recording also falls, although not so rapidly. Therefore, it is not clear a priori, whether it is possible to construct a practically usable star detector whose efficiency would be sufficiently high. To answer this question, it is necessary to investigate the amplitude spectra of pulses arising at the output of the scintillation counter when both π^- mesons and the particles which do not produce stars (e.g. π^+ mesons) come to rest in the scintillator. An effective star detector may be accomplished only if the major part of these spectra turn out to be not overlapped.

2, SPECTRA OF PULSES

To measure the spectra of pulses we made use of the arrangement shown in Fig.1. A collimated beam of 170 MeV π^- mesons from the synchrocyclotron of the Laboratory of Nuclear Problems of JINR passed through a graphite absorber. The π^- mesons slowing down were detected by a telescope consisting of two scintillation counters in coincidence. The plastic scintillators of both counters were $6 \times 6 \times 1.5$ cm^3.

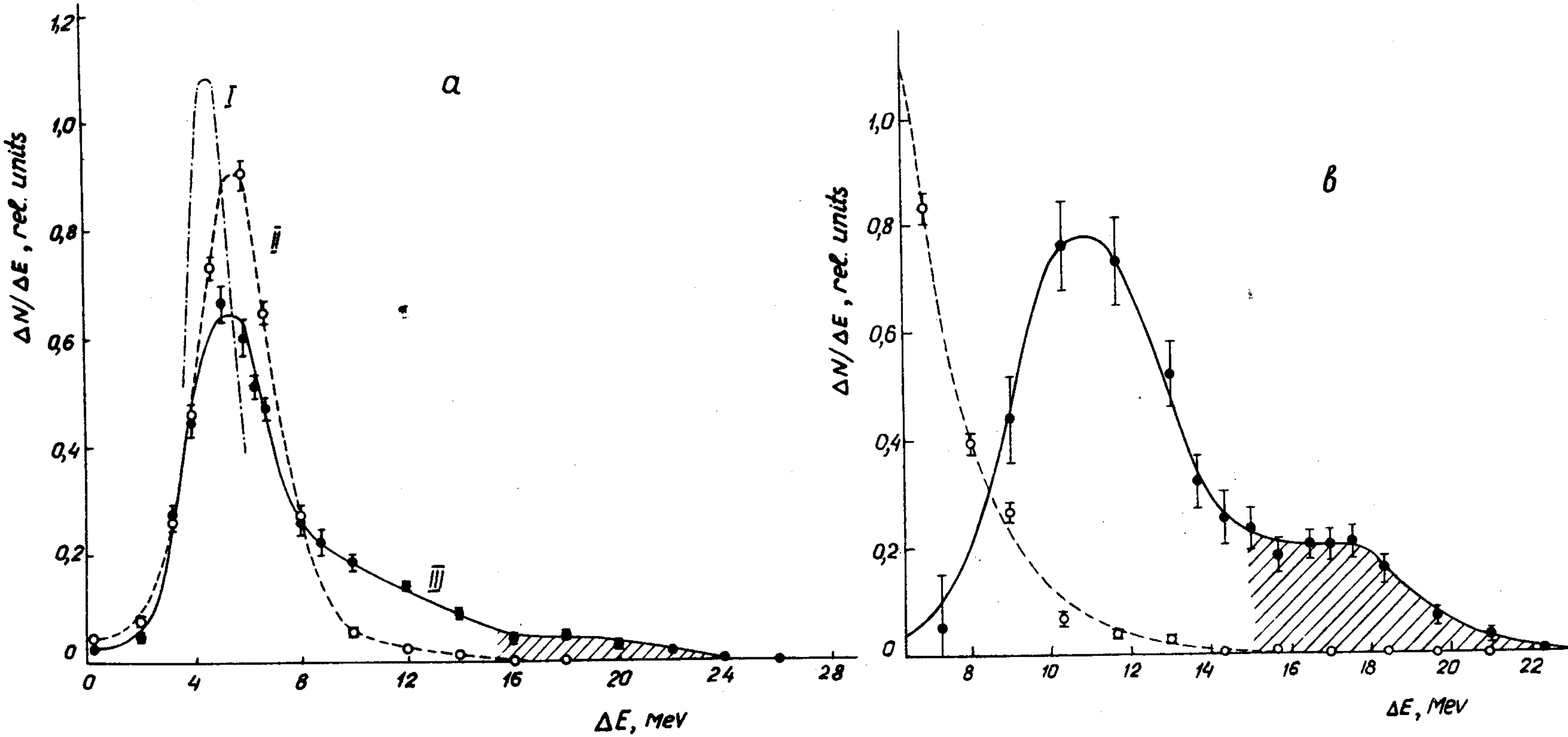


F i g. 1.

Detector scheme. C_1 and C_2 -scintillation counters; c.f. -cathode followers; c.c. -coincidence circuit; sc -scaler; d -variable delay (up to 5.10^{-8}sec) to compensate the time shift of counters C_1 and C_2 with variation of V_2; f -moderating absorbers.

The photomultiplier of the first counter **FEU–33** . worked in the regime of time resolution, the photomultiplier of the second counter **FEU–29** - as a spectrometric one. The coincidence circuit was of the bridge type and employed the semiconductor diodes **D–2A.** The resolving time of the telescope for the coincidences depended upon the length of the pulse forming short-circuited cables and was equal to 10^{-8} **sec.** From the output of the coincidence circuit the pulse was fed to start the pulse height analyzer **AADO–1.** Simultaneously, the pulse to be analyzed from the output of the counter C_2 was applied to the input of this analyzer.

The amplitude spectra of pulses were obtained with three different thicknesses of the absorber (Fig. 2a). The first spectrum of those measured is a comparatively narrow line corresponding to the passage of the particles with relativistic ionization losses through the scintillator. The following spectrum



F i g. 2.

Pulse spectra in counter C_2. The abscissa axis is the energy lost by π^- meson in the scintillator. The spectra are normalized to equal area. Shaded is the region of the spectrum not overlapped with the 'stop spectrum'.

a/ I -pulse spectra from the passing relativistic π^- mesons with the residual range $50 g/cm^2$ of carbon and the range spread equal to $\pm 4 g/cm^2$; II -the spectrum for the residual range $10 g/cm^2$; III -the spectrum corresponding to zero residual range.

b/ ● -pulse spectrum from π^- mesons stopping in the scintillator; ○ - a part of spectrum II.

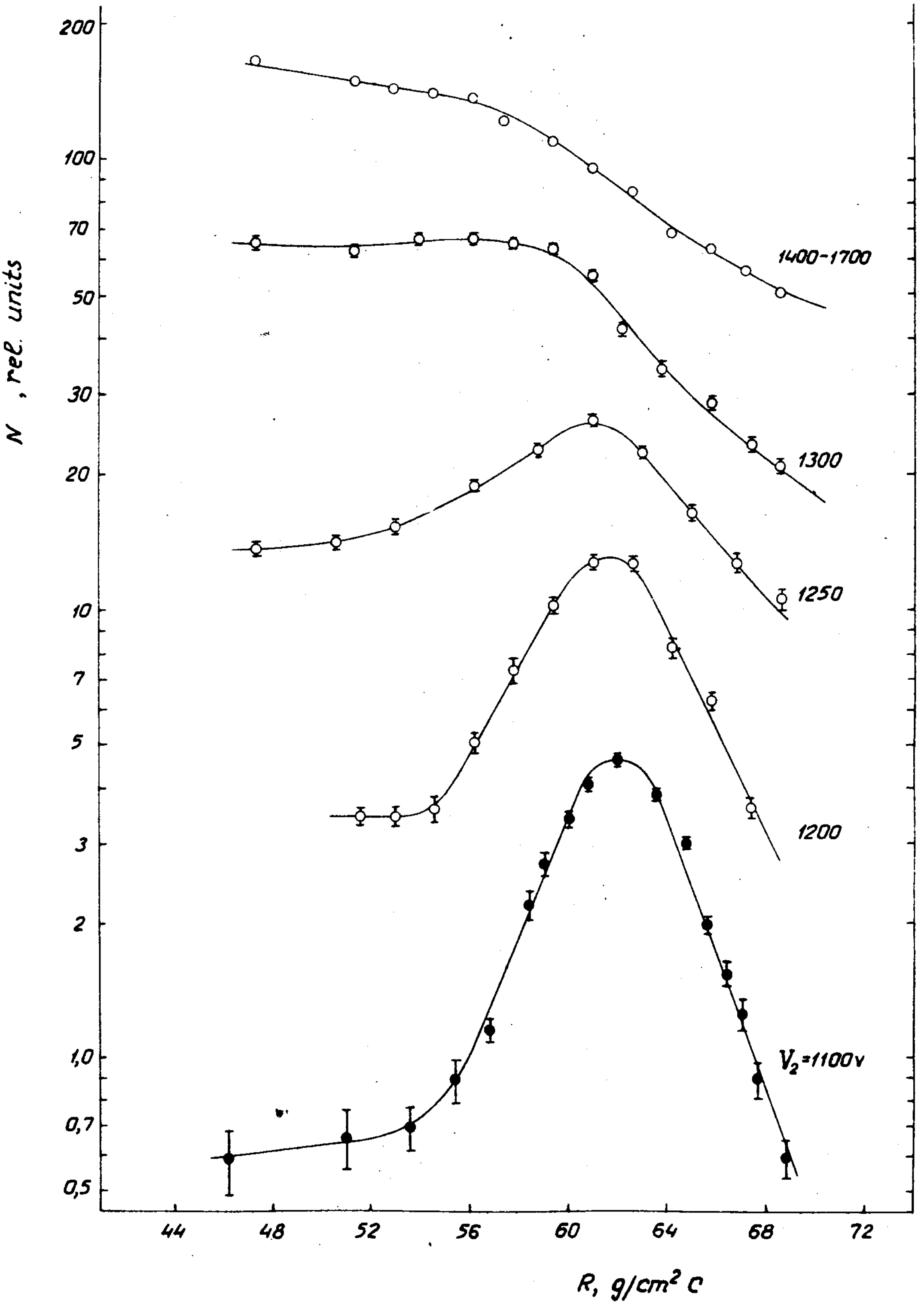
was obtained when such absorber was chosen so as π^- mesons would lose almost all their energy in the detector, but they would not yet stop in C_2. At last, the third spectrum was measured with the thickness of the absorber corresponding to the maximum number of the stops of π^- mesons in the scintillator C_2. At such a position of the absorber *20%* of all the π^- mesons incident on the scintillator stopped in it. The remaining ones passed the scintillator through. The spectrum of pulses corresponding to these passing π^- mesons must have a shape analogous to the second spectrum in Fig. 2a. Therefore, by subtracting the second spectrum from the third one (after the corresponding normalization) it is possible to single out the pulse spectra corresponding to π^- mesons coming to rest only. (Fig.2b).

When π^- mesons stop in the scintillator, the energy is released because of the two processes occurring in succession. Firstly, a π^- meson is slowed down losing rather large energy (≈ 10 MeV in our case) for the ionization of the medium. Then it produces a nuclear disintegration, and the outgoing particles of the star leave a part of their energy in the scintillator. The spectrum presented in Fig. 2b is, therefore, a result of the superposition of two distributions: the 'stop spectrum' and the 'star spectrum' corresponding to the two processes mentioned above. Only the latter of these distributions is characteristic of π^- mesons only. As to the 'stop spectrum', it must be the same both for π^- mesons and for π^+ mesons; for μ mesons it is somewhat displaced to the region of small pulses.

An experimental comparison of the spectra of pulses produced when π^- and π^+ mesons come to rest in the scintillator has been made at the beams of π^- and π^+ mesons having the same average energy (70 MeV) and the same spread of ranges. The comparison has shown that an approximately one third part of the stopping π^- mesons yields the pulses exceeding the maximum pulse of the 'stop spectrum'. It is this part of the spectrum shaded in Fig. 2, that may be used for the work of the telescope in the regime of a star detector. It follows from what has been said that the expected recording efficiency of the stopped π^- mesons must be rather high *(≈ 30%).*

3. EFFICIENCY

In order the telescope shown in Fig. 1 could detect only the stars due to π^- mesons it is sufficient to set at the output of the counter C_2 a discriminator which does not permit small pulses to reach the coincidence circuit. An analogous result may be obtained in a simpler manner by decreasing the voltage V_2 at the photomultiplier of this counter. Fig. 3 shows the change in the characteristics of the detector as the voltage V_2 decreases. (It should be, of course, borne in mind that all the values for V_2 given here and further have a relative character). In this Figure are plotted the results of measurements of π^- meson counting rate N as a function of the thickness of the matter R they traverse (absorber and scintillators). The mean range of π^- mesons was $\approx 62.5\ g/cm^2$ of carbon, that corresponds to an energy of 170 MeV ; the range spread due to the beam being not monoenergetic and to straggling was found to be $\pm 4\ g/cm^2$. In the region of high voltages $V_2 > 1400$ v where the recording efficiencies for the passing and stopping π^- mesons are close to unity, and, therefore, do not change

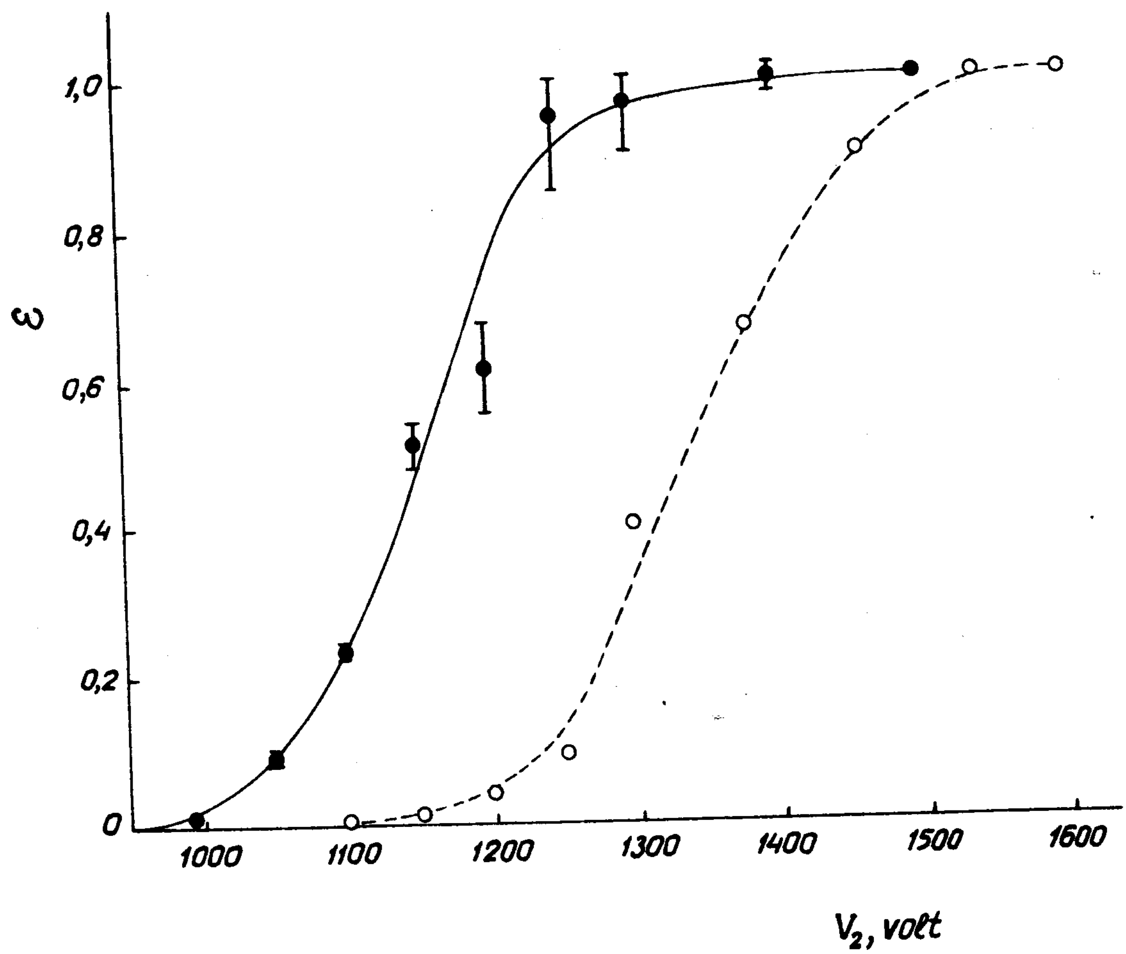


F i g 3.

The dependence of N upon R at various voltages V_2

by varying V_2, the dependence $N(R)$ is an integral range distribution function. When $V_2 < 1400$v, the shape of the curve $N(R)$ is essentially distorted. The counting rate N in the region of thickness $R \leqslant 50$ g/cm^2, where the telescope detects only the traversing π^- meson drops considerably more rapidly with decreasing V_2 than in the region $58 \leqslant R \leqslant 66$ g/cm^2, where besides the passing π^- mesons, those stopped in the scintillator C_2 are detected. The variation of the shape of the curve $N(R)$ with the decrease of V_2 is going on up to $V_2 = 1100$ v. By a further diminishing of the voltage the shape of the 'peak' alters no longer, and only an identical decrease in the magnitudes of N takes place for all the values of R. In this voltage region the curve practically coincides with the differential range distribution function.

Being aware of the range distribution function of π^- mesons it is not difficult to obtain from the dependences $N(R)$ the magnitudes of the recording efficiency of the passing (ε_o) and stopping



F i g. 4.

Detector efficiency. ⫶ – ε_{st} ; o – ε_o . *The efficiency* ε_o *was measured for* π^- *mesons with residual range equal to* 10g/cm^2 C.

(ε_{st}) π^- mesons. In calculating these efficiencies (Fig.4) use was made both of the curves from Fig.3 and of an analogous ones measured at the 67 MeV π^- meson beam. As is seen from Fig. 4, at first the efficiency ε_0 drops with decreasing the voltage V_2 much quicker than ε_{st} in agreement with the spectra given in Fig. 2. However, at low voltages the rise of the ratio $\varepsilon_{st}/\varepsilon_0$ becomes slower, and for $V_2 \leqslant 1100$ v, the magnitude of this ratio is no longer dependent upon V_2 (Fig.5). Such a behaviour of $\varepsilon_{st}/\varepsilon_0$ can be easily understood if we take into account that π^- mesons produce stars both when they are brought to rest in matter and in flight. The ratio of the probabilities for these two processes for our scintillator equals approximately 50, that is close to the value of $\varepsilon_{st}/\varepsilon_0$ obtatained for small voltages where the detector is sensitive only to stars.

The ratio $\varepsilon_{st}/\varepsilon_0$ changes with decreasing V_2 in another way when the detector records π^+ mesons (Fig. 5). In contrast to π^- mesons, π^+ mesons give rise to stars only in flight. Therefore, the magnitudes of $\varepsilon_{st}/\varepsilon_0$ for π^+ and π^- mesons coincide only in the range of large values for V_2, where the detector effectively records the pulses belonging to the 'stop spectrum'. When one goes over to the region of voltages where the detector is sensitive only to stars, the efficiency ε_{st} for π^+ mesons falls, and the ratio $\varepsilon_{st}/\varepsilon_0$ decreases rapidly.

A comparison of the curves given in Fig. 5 shows that the telescope begins to work in the regime of a star detector at the voltages $V_2 \approx 1100$ v. The efficiency ε_{st} corresponding to this voltage is equal approximately to 30%, what is close to the estimate obtained earlier from the analysis of the spectra. The recording efficiency for the π^- mesons coming to rest in the scintillator ε_{st} should not be confused with that for π^- mesons incident on the detector input w , which, in our case, is considerably lower than ε_{st} due to the disappearance of mesons when they are passing through the absorber of the detector, and due to a comparatively small thickness of the scintillator. If we use a thick scintillator, i.e., whose thickness is close to the spread of π^--meson ranges, then the latter factor from those mentioned above is removed. In this optimal case the ratio w/ε_{st} is found to be 70% at an energy of π^- mesons being 65 MeV, and 40% – at 170 MeV.

A star detector employing a thick scintillator may be used in experiments where a high efficiency of π^- meson recording is required. If the range curve of π^- mesons is necessary to be measured, the thickness of the scintillator should be taken small compared with the range spread. Typical range curves which are available when the telescope works as a star detector are presented in Fig. 6. These curves have been measured at two different beams of π^- mesons with the mean energies of 67 and 170 MeV.

4. SELECTION CHARACTERISTICS OF THE DETECTOR

Since the star detector detects only high energy stars produced by stopping π^- mesons, it is little sensitive to other particles which do not create such stars. The selection ability of the star detector is convenient to be characterized by a selection coefficient K, which is the ratio of the recording efficiency for π^- meson stops to that of other particles both coming to rest in the scintillator (K_{st})

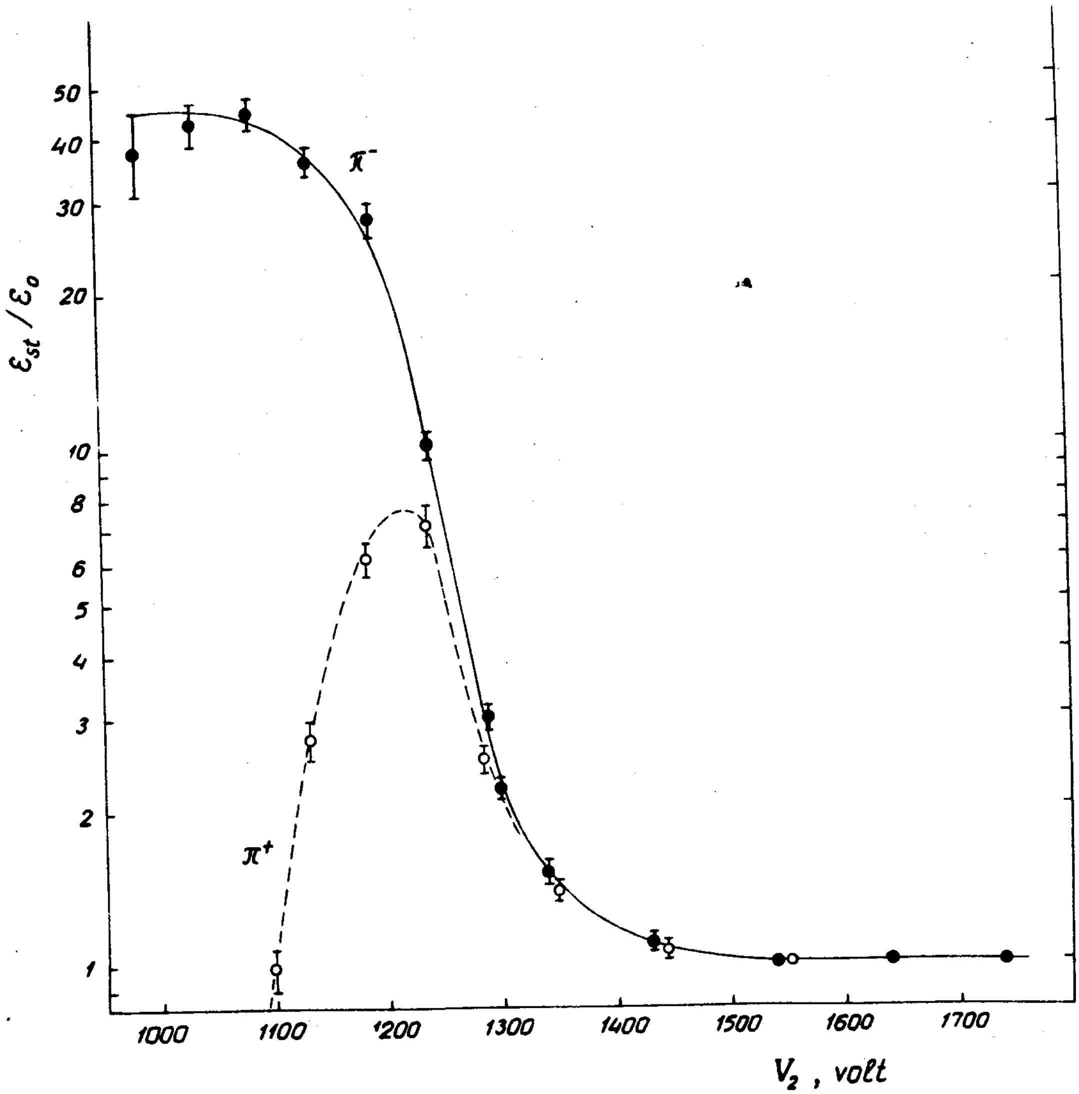


Fig 5.

The ratio $\mathcal{E}_{st}/\mathcal{E}_o$. -for π^- mesons; -for π^+ mesons.

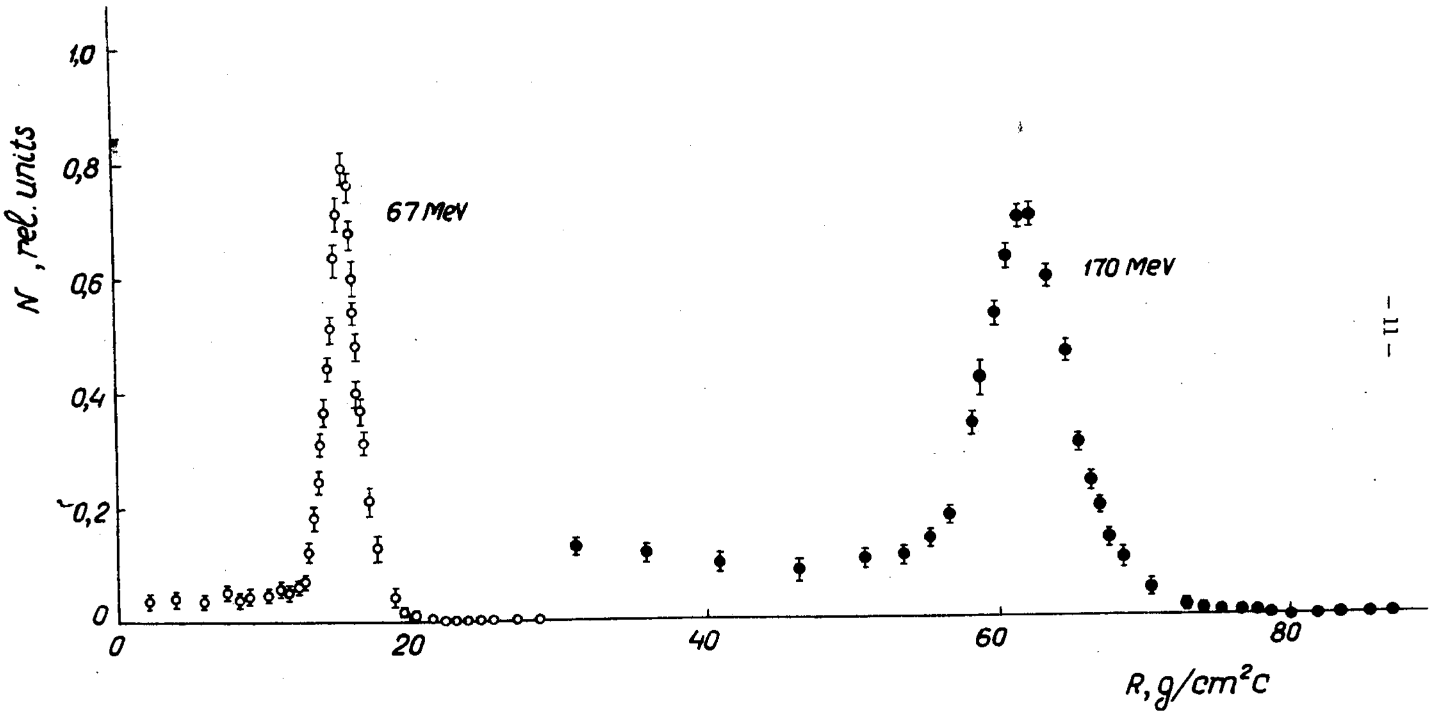
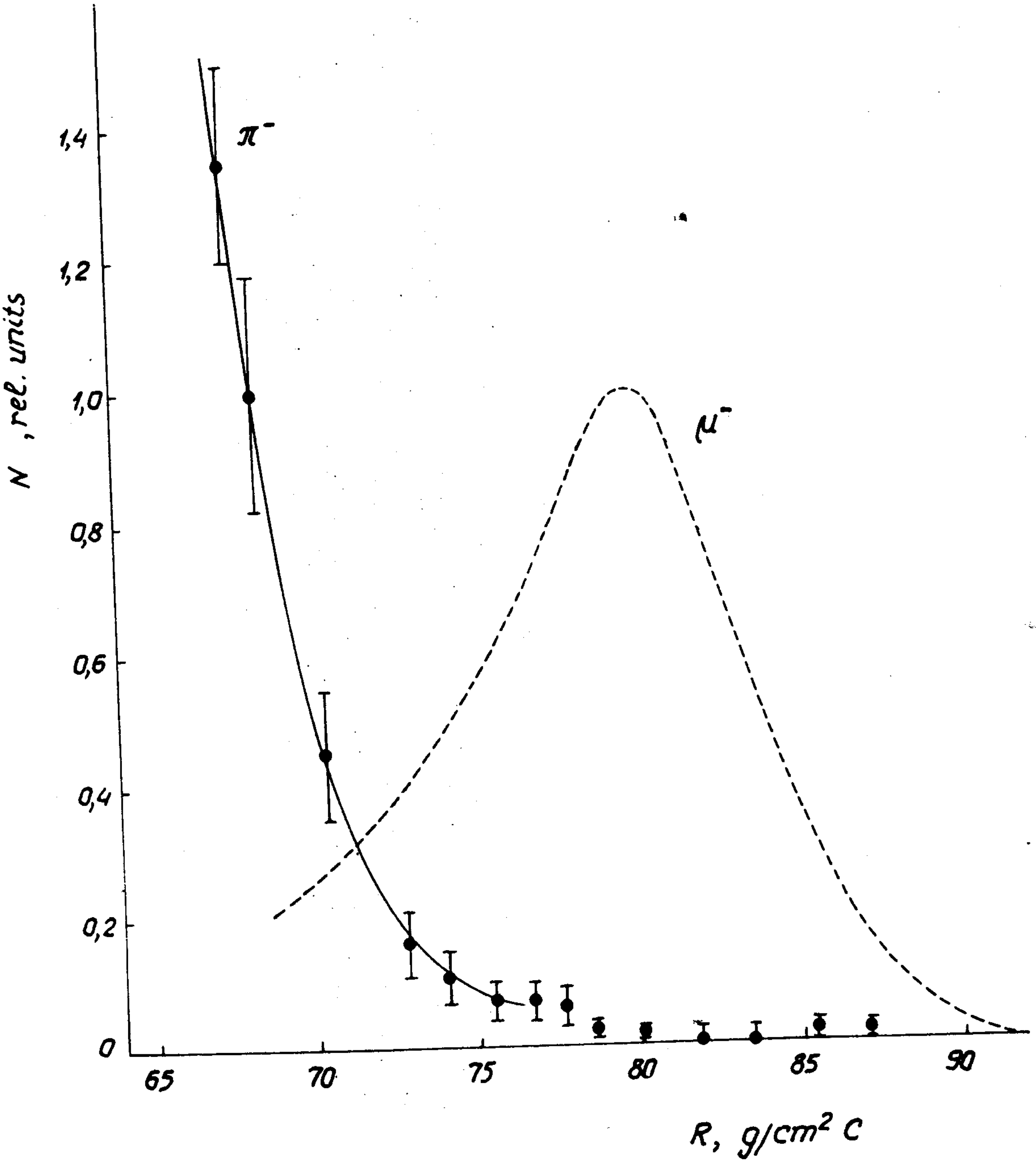


Fig 6.

Range curves for π^- meson beams at energies of 67( ) and 170 MeV( ); V_2 = 1100 v.



F i g. 7.

G

Inefficiency of the star detector to μ^- mesons. ⌶ - the measured range curve. The real μ^- meson range curve is shown by the dashed line. V_2 = 1100 v.

and those passing through the detector (K_0).

μ mesons and electrons fail to produce high energy stars either in flight, or by the stopping. (When coming to rest in matter possessing large atomic weight μ^- mesons may give rise to stars, but with a small energy release). Therefore, the selection coefficients K_{st} and K_0 for light particles may be made whatever large by decreasing the voltage V_2, with $K_0 \gg K_{st}$. Fig. 7 shows a part of the measured by the star detector range curve of 170 MeV π^- mesons and μ^- mesons contaminating this beam. If the efficiency of μ^- meson detection were the same like for π^- mesons, i.e., $K_{st} = 1$ then the measured range curve in the region of large thickness would coincide with the dashed line drawn in the Figure. As is seen from this Figure, in this region there is no maximum, here $K_{st} \gtrsim 30$ So, already at the voltage V_2 being 1100 v, i.e., near the limit of the regime of the star detector, the selection for μ^- mesons is characterized by a large magnitude of K . This result is likely to concern μ^+ mesons as well. The magnitude of K for electrons must be still greater than for μ mesons in view of small energy release when the electrons pass through the scintillator.

The selection in case of the passing π^+ mesons is characterized, according to the measurements, by the same magnitude of $K_0 \approx 50$, as in case of π^- mesons. Note, that the magnitude of K_0 must be analogous for other nuclear-active particles since all of them are responsible for star production in flight with about the same probability. The magnitude of K_{st} for π^+ mesons was found to be close to that obtained for μ mesons (see Fig. 8). Like in case of μ mesons it may be made very large by decreasing V_2.

The sensitivity of the star detector to the particles heavier than π mesons has not been investigated. Here we only note that the magnitude of K_{st} must decrease with the rise of the particle mass.

5. MODIFICATIONS OF THE DETECTOR

As it was pointed out above, the upper limit of the voltage where the telescope can work as a star detector turns out to be V_2 $1100–1150$ v. If we increase the voltage by $50-100$ v, the detector starts to record the pulses due to the 'stop spectrum'. Here, as is seen from Figs. 4 and 5, the recording efficiency for the stops ε_{st} may be found to be close to unity while the ratio $\varepsilon_{st}/\varepsilon_0$ remains still large. The telescope working in this regime (we shall call it a 'stop detector') unlike the star detector is equally sensitive to π^- mesons and to π^+ , μ^- and μ^+ mesons (Fig. 9).

When the intensity of the π meson beam is $\approx 10^4$ sec^{-1}, the counting rate of the stop detector amounts to some hundred counts per second. Such large counting rate allows to make the measurements of the range curves $N(R)$ automatic. This presents considerable advantages in the case when in the course of an experiment it becomes necessary to control the magnitude of the beam energy frequently and quickly. For registering the range rurve a self-recording integrator was connected to the output of the coincidence circuit. The motor of this integrator rotated synchronously with that moving the wedge-shaped absorber (Fig. 1). A typical range curve thus measured is given in Fig. 10. All the measurement procedure takes some minutes only.

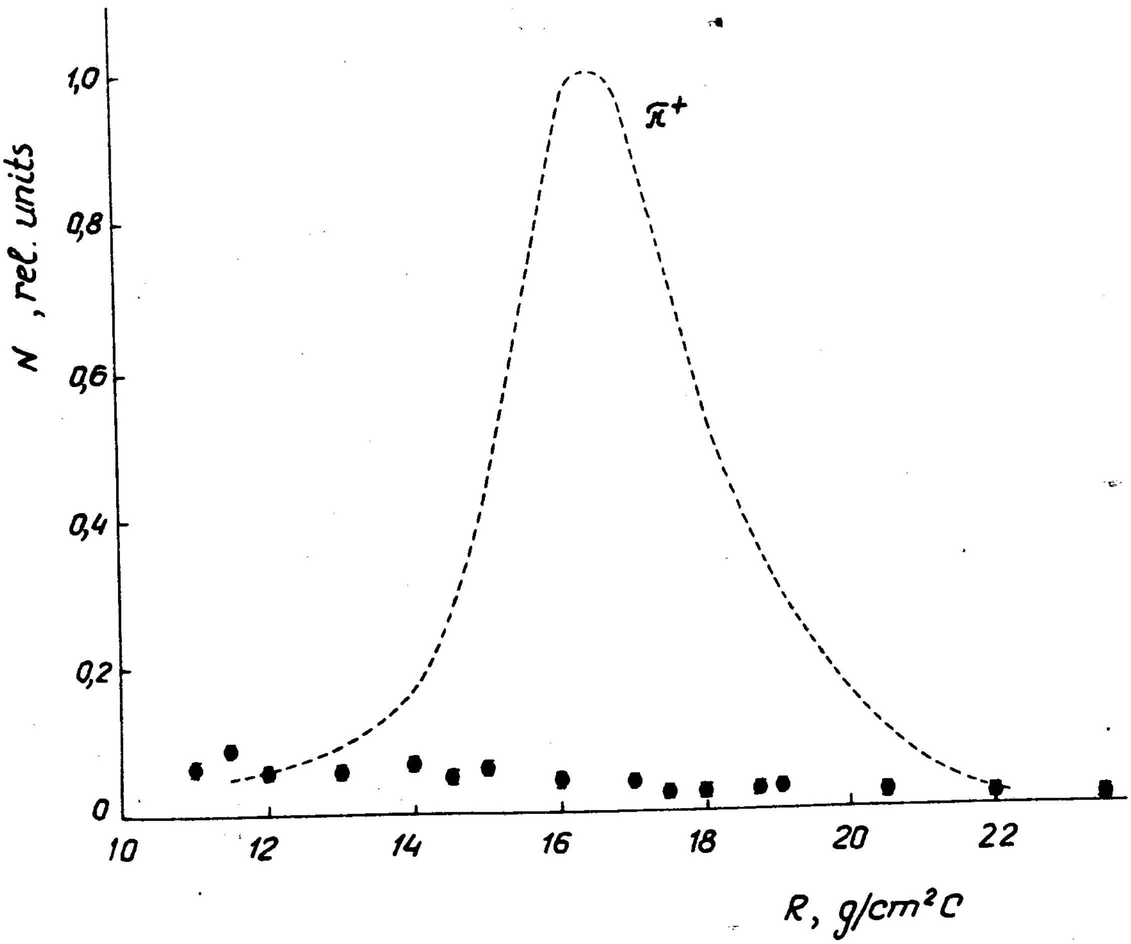
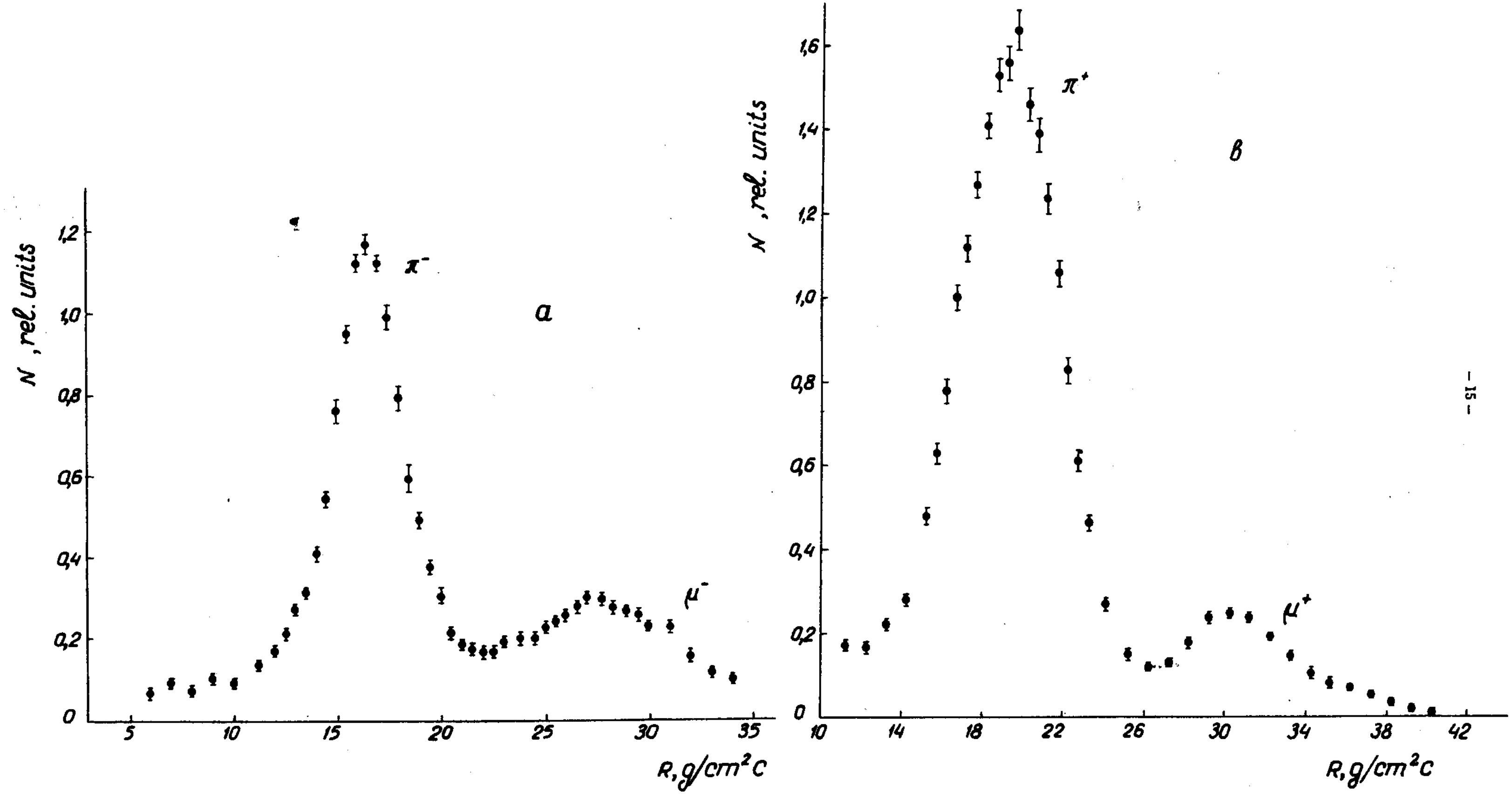


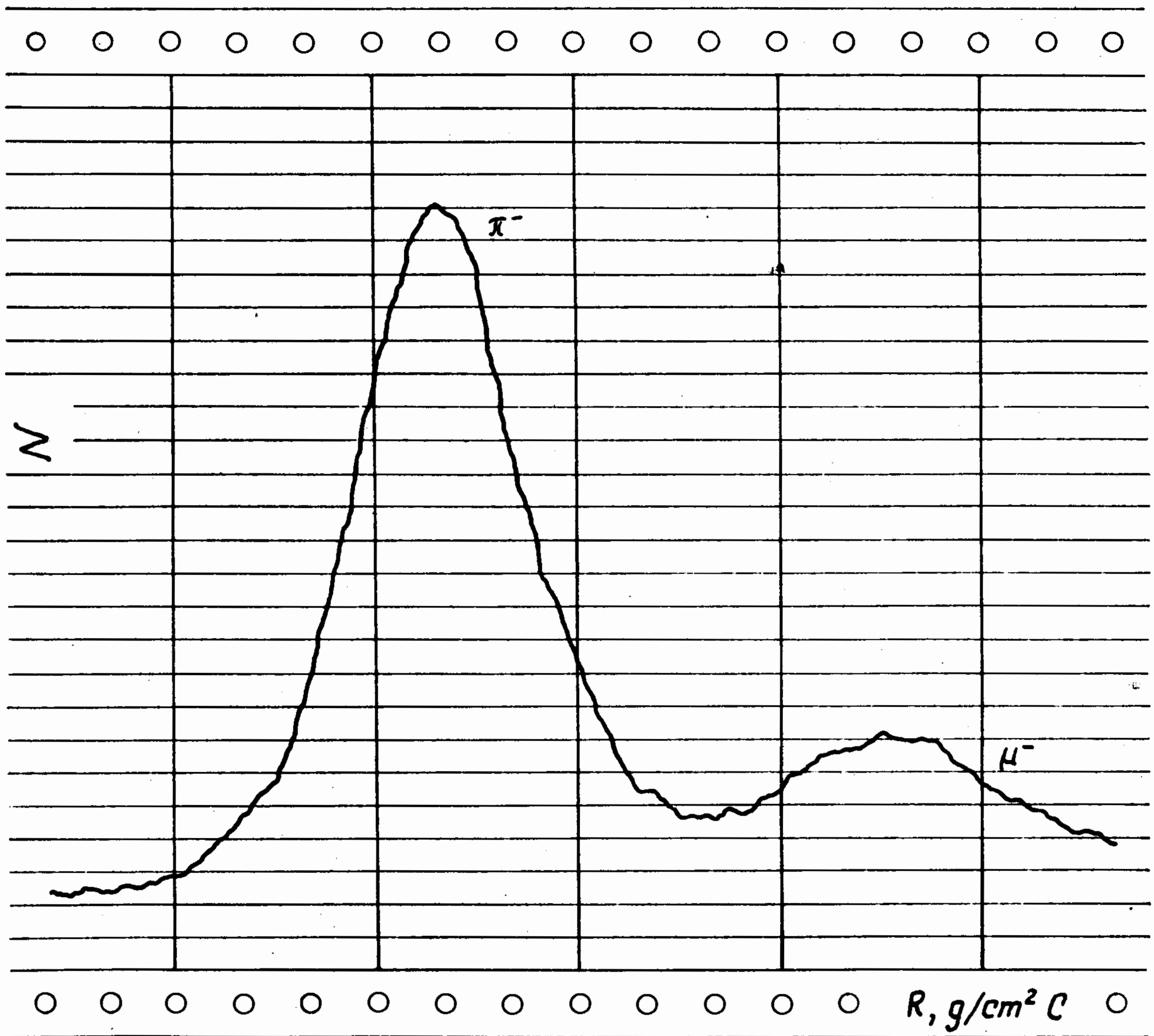
Fig 8.

The same as in Fig. 7, but for π^+ mesons of 67 MeV mean energy.



F i g. 9.

Range curves measured by means of the stop detector. a —for the beam of π^- and μ^- mesons with the momentum 150 MeV/c. (π^- meson energy is 67 MeV). b —for the beam of π^+ and μ^+ mesons with the momentum 163 MeV/c. V_2 = 1250 v.



F i g. 10.

Range curve registered on the record chart of the self-recording integrator. $V_2 = 1250$ v.

The pulses in the counter C_2 detected in the regime of a star detector are so large that they essentially exceed all the outside pulses due to the background which is present in the experimental hall of the accelerator when working with the π^- meson beams. This allows to simplify the scheme of the star detector by excluding the counter C_1 and by connecting the input of the scaler directly with the output of the counter C_2. The range curve of 70 MeV π^- mesons measured by means of such a simplified detector consisting of only one counter, was found to be not very much different from the real range curve. However, the star detector consisting of only one counter could be hardly used for work under more difficult background conditions than in our case (e.g., in the proton or neutron beam).

Finally, let us point to one more modification of the star detector scheme. This modification consists in replacing the counter C_2 for the counter analogous to C_1, i.e., with a good time resolution but having a comparatively bad spectrometric characteristics. In this case so large a value for the ratio $\varepsilon_{st}/\varepsilon_0$ as that presented in Fig. 5 is impossible to obtain; it is found to be *10–20*. However, the star detector of such a simplified form has a practical advantage. It does not differ in anything from 'standard' scintillation telescopes. So, the latter ones may be used as a star detector without essential changes for rough measurements of the range curve of π^-mesons.

6. CONCLUSION

An investigation of the characteristics of the detector shows that the region of its working voltages is separated into three essentially different parts. When the voltages are low, the telescope works in the regime of a star detector, distinguishing π^- mesons coming to rest in the scintillator from other stopping and passing particles. The region of voltages corresponding to this regime is **150–200 v** for the type of the photomultiplier we have chosen. Higher voltages of *1200–1270* **v** correspond to the regime of the stop detector. In this case the detector records the stops of π and μ mesons of both signs equally well Finally, in the region of still higher voltages $(V_2 > 1400 \text{ v})$ the detector works as a 'usual' telescope which does not possess any selection properties.

The detector described may be used as a spectrometer which allows to measure the spectra of π^--mesons under the conditions of large outside background. It is most reasonable to apply this detector for investigating the spectra of π^- mesons in the low energy region $(< 50 \text{ MeV})$ where the magnetic spectrometer is usually difficult to apply because of the large μ meson background.

It should be noted in conclusion that because of its simplicity the star detector possesses good operation characteristics. It can be easily adjusted and works stably; for the time of its operation (about a year) its parameters do not undergo any noticeable changes.

REFERENCES

1. A.F. Dunaitzev, Yu.D. Prokoshkin, Tang Syao-wei. Pribory i tekhnika eksperimenta, 1960 (in press); Proceedings of the International Conference on High-Energy Accelerator and Instrumentation. p. 592, 1959. CERN , Geneva.

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