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Abstract

A relative probability of the $K_2^0 \rightarrow e^{\pm} + \pi^{\mp} + \nu$ *decay has been estimated by using the cloud chamber with the plate. It constitutes* $(46 \pm 11)\%$ *with respect to all the decays into the charged products. There have been found four electron-positron pairs with large opening angles, and the analysis of these pairs has been made. It has been shown that these events should be treated as a direct experimental indication to the existence of the* $K_2^0 \rightarrow \pi^0 + \pi^0 + \pi^0$ *decay so far unobserved. The absolute probability of the* $K_2^0 \rightarrow e^{\pm} + \pi^{\mp} + \nu$ *decay (with account of the fraction* $K_2^0 \rightarrow 3\pi^0$ *) which was found by the mean lifetime of the* K_2^0 *is in agreement, within experimental error with the twofold absolute probability of the* $K^+ \rightarrow e^+ + \pi^0 + \nu$ *decay, what points to the extension of the selection rule* $\Delta I = \frac{1}{2}$ *to the leptonic decays of* K *-mesons. The estimation of the absolute probability of the* $K_{\mu 3}$ *decay also agrees with the selection rule mentioned above.*

Gell-Mann and Pais[1] were the first to point to the isotopic spin selection rule for decay processes of hyperons and K - mesons. They suggested that in case of non-leptonic decays the isotopic spin changes by ½. It was shown further that the decays involving the strongly interacting particles are satisfactorily described within the measurement error by the selection rule $\Delta I = \frac{1}{2}$. (see, for example, the review[2]).

Later on Okun'[3] considered this rule in the framework of the compound model of elementary particles which was proposed by Sakata[4]. According to this model, nucleon and Λ^0 - hyperon are assumed to be 'true-elementary' particles. It was also shown by Okun' that if one restricts oneself to the four-fermion interaction, then the $\Lambda^0 \rightarrow p + e^-(\mu^-) + \nu$ decay in which the isotopic spin of strongly interacting particles changes by ½ is a basic one. By using the above-mentioned process in the framework of Sakata's model all other leptonic decays of strange particles may be deduced. Hence there appears a possibility of extending to the K_{e3} and $K_{\mu 3}$ decays the selection rule $\Delta I = \frac{1}{2}$ which yields the relationships for the absolute probabilities of decays

$$w(K_{e3}^0) = 2\,w(K_{e3}^+)\,, \tag{1}$$

$$w(K_{\mu 3}^0) = 2\,w(K_{\mu 3}^+)\,. \tag{2}$$

The same conclusion was drawn by Okubo and Marshak[5] under more general assumptions that the transformation properties in the isotopic space for strange particles weak interactions involving leptons and without them are identical. The first attempt to check the selection rule $\Delta I = \frac{1}{2}$ both for leptonic and non-leptonic decays of K mesons has been made by Kobzarev and Okun'[6], and Okubo et al[7], who calculated the mean lifetime of the K_2^0 by the experimental data on the K^+ decays. The magnitude obtained turned out to be little different from the experimental value.

However, a straightforward comparison of the absolute probabilities of the leptonic decays of the K

mesons (a check of the validity of (1) and (2)) has not been yet been yet made[1] because of the absence of the experimental data on the K_2^0 decays. In the paper by Bardon et al/9/ in which the cloud chamber was used some events of the K_{e3}^0 and $K_{\mu 3}^0$ decays of the K_2^0 were identified according to the kinematics of V^0 - events and the ionization measurements. However, as the authors themselves point out, they failed to estimate whatever exactly the relative probabilities of the decay modes under consideration.

This investigation is a part of the study of the decaying properties of the K_2^0 by the cloud chamber It was performed with the Joint Institute for Nuclear Research synchrophasotron[2]. The aim of this investigation is to determine the absolute probability of the $K_2^0 \rightarrow e^{\pm} + \pi^{\mp} + \nu$ decay and to estimate the probability of the $K_{\mu 3}^0$ decay.

To identify the decays we placed a lead plate 5.8 g/cm^2 thick into the chamber perpendicular to the beam of the K_2^0 . The K_{e3}^0 decays were effectively selected by measuring the momentum losses of decaying particles in the K_2^0 decay since the probability of large energy losses by electrons for radiation in traversing the plate is great. For instance, this probability is 0.86 for the emission losses of more than 30% of the initial electron energy. The experimental arrangement is presented in Fig. 1. An internal lead target (20 x 25 x 70 mm^3) placed into a proton beam with an energy of 9 BeV is a source of the K_2^0 . The particles, emitted at an angle of 97° to the direction of the proton beam are going through a window in the wall of the accelerator vacuum chamber, through a lead convertor 50-100 g/cm^2 thick and through a 3x12 cm^3 lead collimator 15 meters long placed in the aperture of the iron yoke of the synchrophasotron. Then the beam of particles pases between the pole tips of 10000 gauss clearing magnet. Further the beam passes through the second 5x20 cm^2 lead collimator 1.5 meters long which is made in the concrete shielding, and strikes the cloud chamber placed in the gap, of the 15000 gauss electromagnet. The distance from the end of the last collimator to the chamber is longer than 1 m. Therefore, all the K_1^0 produced in the walls of the collimator decay before they reach the chamber. The chamber is placed at a distance of 8 m from the internal target. It has been described in detail earlier/12/. In our experimental arrangement the depth of the illuminated region has been increased by making the gap between the windings of the magnet larger (up to 9 cm). The average value of the magnetic field in the illuminated region was found to be 15000 gauss, the inhomogenuity of the field being less than 4%. The cylindrical glass of the chamber is 2 g/cm^2 thick. The chamber was triggerred every seventh pulse of acceleration and started by a pulse generated by the high-frequency system of the accelerator as early as 40-60 msec before the accelerated particles strike the target. The internal target was operated by a special programming device providing for a simultaneous or alternative work of several targets. The control of the chamber and other registering apparatus (television screen, the monitor, the control for the target operation etc.) were removed from the synchrophasotron hall, in a place safe from radiation.

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[1] At attempt to determine experimentally the total probability of the leptonic decays of the K_2^0 was made in the investigation by Crawford et al/8/ in which only 8 leptonic decays of the K_1^0 and K_2^0 have been observed.

[2] Some of the results of this investigation has been published/10/ and reported at the Rochester Conference. However, in the Proceedings of this Conference /11/ they appeared considerably distorted.

Experimental Results

There have been taken about 12 thousand photos on which 670 V^0 events and one four-prong star have been recorded. About 40 events are identified as decays of the Λ^0 - particles produced by the K_2^0 in the lead plate and in the chamber wall. The remaining V^0 events are the K_2^0 - decays. There were observed in each photo ~ 10 protons knocked out from the chamber wall, the mean intensity of the accelerated protons being 5.10^8 particles per pulse. The number of electron pairs recorded was approximately three times less than that of the V^0 - events, among them only four pairs make large angles with the direction of the K_2^0 beam. This shows that the background of the γ rays was insignificant and allowed to record the Dalitz pairs resulting from the neutral $K_{3\pi}^0$ decay. Among 440 K_2^0 - decays registered during the exposure of the chamber with the lead plate there were detected 114 events of the passing particles, provided the decaying particle can appear after the plate in the illuminated region. The examples showing the 'passing' of the decaying particles (π^- and e^-) through the plate are given in Fig s. 2 and 3.

For all the passing particles there have been measured the momentum of the decaying particle before and after the passing through the plate, the angle at which the particle enters the plate, the angle at which the particle leaves the plate, as well as the momentum of the secondary decaying particle/3/. As a result it has been found that in 18 events the decaying particle undergoes a momentum loss of more than 30%, in five events it stops in the plate, and in one event it gives rise to a visible star. At the same time, in all the cases (as one can see from Table 1 in which are listed the measured momenta) the momentum loss or the stopping of the particle cannot be accounted for by the ionization losses. In six events showers having two and three electrons have been observed. For these events, in the second column of the Table the averaged energies of the shower particles are indicated. Obviously, all the selected events with the momentum loss of more than 30% should be identified as electron 'passings'. The five stopping events may be both the electron stoppings and zero-prong stars produced by pions. In order to find the real number of electron passings through the plate it is necessary, first, to correct for the momentum loss of less than 30%, and, second, to exclude the zero-prong stars due to pions from the number of stoppings. The first correction was found for each event by the formulae for the distribution of the probability of the evergy loss for electron by radiation and by ionization (see the paper by Eyges/13/).It makes three events to be added. The second correction was taken to be equal to the number of nuclear interactions of all the traversing decaying particles (with the exception of electrons and muons) with the lead nuclei, the cross section being assumed to be equal to a geometric one/4/. This correction includes three events. Thus, the real number of electron passings is 24. To determine the relative probability of the K_{e3}^0 decay a correction should be also introduced for the motion of the decaying K_2^0 mesons. As can be easily seen, the motion of the K_2^0 leads to a certain increase of the number of passings through the plate of heavier decaying particles (π and

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3/ The error in the momentum measurement is less than 10%.

4/ A rough estimate of the number of muons traversing the plate yields ~ 25. The correction for the seeming stoppings due to elastic pion scattering is negligibly small.

μ mesons) if compared with the number of passings of lighter decaying particles (electrons and neutrinos). Evidently, this correction is equal to the ratio of the values of solid angles for the decaying pions and electrons in the rest system of the decaying K_2^0 -mesons (the decaying particles traverse the plate when being inside these solid angles). To find the correction we made use of a value equal to 135 MeV for the mean energy of the decaying K_2^0 particles. This value has been determined by the data of the momenta measurements (given in the Table) under the assumption that in the K_{e3} decays the energy spectra of electrons and neutrinos are identical. As a result, it was found that due to the motion of the K_2^0 the number of passings of electrons through the plate decreases as much as 1.1 times.

In Fig. 4 the value of the correction is plotted against the K_2^0 energy. It can be seen from this plot that we do not make a noticeable error when making use of the value equal to 135 MeV for the mean energy of the K_2^0 mesons[5].

Finally, we have found that the corrected number of events with electron 'passings' is 26. It is consistent with a magnitude of the probability of the K_{e3}^0- decay (with respect to all the decays having charged products) $q = 0.46 \pm 0.11$. The quoted error is taken to be a root mean-square one made up of the statistical error and of errors which are obtained during the identification of the events and introduction of the corrections.

The observation of four (e^+e^-) - pairs interpreted as Dalitz pairs from the $K_2^0 \to 3\pi^0$ decay (which will be discussed about below) presents a possibility of estimating the relative probability of this decay (the efficiency of recording the Dalitz pairs is obtained to be 75% under our conditions). This estimation yields the value $\frac{w(K_2^0 \to 3\pi^0)}{w(K_{e3}^0)+w(K_{\mu 3}^0)+w(K_{3\pi}^0)} = (0.18 \pm 0.09)$[6]. Hence, one can determine the probability of the $K_2^0 \to e^\pm + \pi^\mp + \nu$ decay in respect with all the K_2^0 decays (0.38 ± 0.10) and being aware of the K_2^0 lifetime $\tau_{K_2^0} = (6.1 \pm^{1.6}_{1.1}) \times 10^{-8}$ sec one can find the absolute probability of the K_{e3}^0 decay to be:

$$w(K_{e3}^0) = (6.2 \pm 2.0) \times 10^{+6}\ \text{sec}^{-1}.$$

The relative probability of the $K_2^0 \to 3\pi^0$ decay can be also estimated by assuming that the selection rule $\Delta I = 1/2$ holds for the $K \to 3\pi$ decays. It follows from this rule that the absolute probabilities of the $K^+ \to 3\pi$ and $K_2^0 \to 3\pi$ decays are equal, as well as the ratio relation between the $K_2^0 \to \pi^+ + \pi^- + \pi^0$ and $K_2^0 \to 3\pi^0$ decays[6,7]. Under this assumption, by using the experimental values of the probability of the $K^+ \to 3\pi$ decay (7.7 ± 0.7) %[14] and the mean lifetime $\tau_{K^+} = (1.21 \pm 0.01) \cdot 10^{-8}$ sec , we get for the relative probability of the $K_2^0 \to 3\pi^0$ decay (0.30±0.03) while for the absolute probability of the $K_2^0 \to e^\pm + \pi^\mp + \nu$ decay we obtain (5.8 ± 1.8) . 10^6sec^{-1}.

It can be easily seen that the absolute probability of the K_{e3}^0 decay we have found by both ways is in agreement within the experimental error with the twofold probability of the corresponding decay of the

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[5] This value of the mean energy of the K_2^0 particles is somewhat overestimated.

[6] As is seen from the consideration of the characteristics of these pairs, the above value may appear to be overestimated.

K^+ meson ($2\, w\, (K^+_{e3}) = (8.4 \pm 1.2) \cdot 10^6\ \mathrm{sec}^{-1}$ /14,15/. This agreement points to the extention of the selection rule $\Delta I = ½$ to the leptonic K_2^0 - meson decays. However, for a final confirmation of this rule it is necessary to make a statistically improved measurement of the relative probability of the K^o_{e3} - decay and of the mean lifetime of the K_2^o 7/.

It should be emphasized that the observation of one four-prong decay and four electron-positron pairs with large opening angles permits to estimate experimentally the fraction of the K_2^0 - decay into three pions. If all four pairs the characteristics of which are given in Table 3, are considered to be Dalitz pairs from the $K_2^0 \rightarrow 3\pi^0$ decay, then we find that the total number of $K^0_{3\pi}$ decays is about 30% of the total number of the K_2^0 - decays what does not contradict the selection rule $\Delta I = ½$, which requires an identity of the absolute probabilities of the $K^+ \rightarrow 3\pi$ and $K_2^0 \rightarrow 3\pi$ decays. The magnitude of the absolute probability of the $K_2^0 \rightarrow \mu^{\pm} + \pi^{\mp} + \nu$ decay found by the experimental values of the probabilities of the K^0_{e3} and $K^0_{3\pi}$ decays is equal to (5.6 ± 3.0). $10^6\ \mathrm{sec}^{-1}$ and agrees within experimental error with the value of the twofold probability of the $K^+_{\mu 3}$ decay (6.8 ± 0.8) . $10^6\ \mathrm{sec}^{-1}$.

An analysis of electron pairs with large opening angles is, undoubtedly, of interest from the point of view of proving the existence of the $K_2^0 \rightarrow 3\pi^0$ decay. Out of the four pairs presented in Table 2, we have little doubts as to the identification only in the third case for which we failed to make accurate ionization measurements for decaying particles because of the background conditions. In the remaining cases the identification does not arouse any doubts.

What is the nature of these pairs ?

The fourth pair may be in principle a result of the conversion of the 'beam' γ - quantum in the chamber gas since the probability that one of the electron pairs observed in the direction of the incident beam has an opening angle of more than (20 - 25)° is 0.6 8/. This cannot account for the nature of the first two pairs in view of large emission angles. Nor can their origin be explained by the conversion of the background γ quanta since otherwise there must have been observed some hundred pairs with smaller opening angles. The electron-positron pairs we have recorded cannot be also Dalitz pairs from the decay of neutral pions produced in the chamber by 'beam' neutrons since there was recorded not a single star which would have had an electron-positron pair. Besides, the estimate made according to the observation of charged pion production shows that the probability of observing one Dalitz pair from a neutral pion decay produced in the zero-prong star is less than 10^{-2}. At the same time the decay of the K_2^0 into neutral pions accounts well enough for all the characteristics of the Dalitz pairs observed.

Since we failed to record a single decay of the long-lived K_2^0 meson into π^+ and π^- the $K_2^0 \rightarrow 2\pi^0$ decay seems to be extremely unlikely. The probabilities of other neutral decay of the K_2^0

7/ The value $\tau_{K_2^o}$ we used is a mean weighted one by the results of two measurements /8,9/; strictly speaking neither of these measurement is direct.

8/ This probability was found from the distribution calculated by Borsellino /16/.

accompanied by the emission of neutral pions (e.g., $K_2^0 \to 2\pi^0 + \gamma$) are also very small.

Thus, there are grounds to treat the pairs we recorded to be the Dalitz pairs from the $K_2^0 \to 3\pi^0$ decay. Therefore, the very fact of their discovering may be regarded as a direct experimental indication to the existence of this type of decay. This is also supported by the observed ratio of the number of the Dalitz pairs to the four-prong event which results from the $K_2^0 \to \pi^+ + \pi^- + \pi^0$ decay accompanied by a Dalitz pair/10/ 9/.

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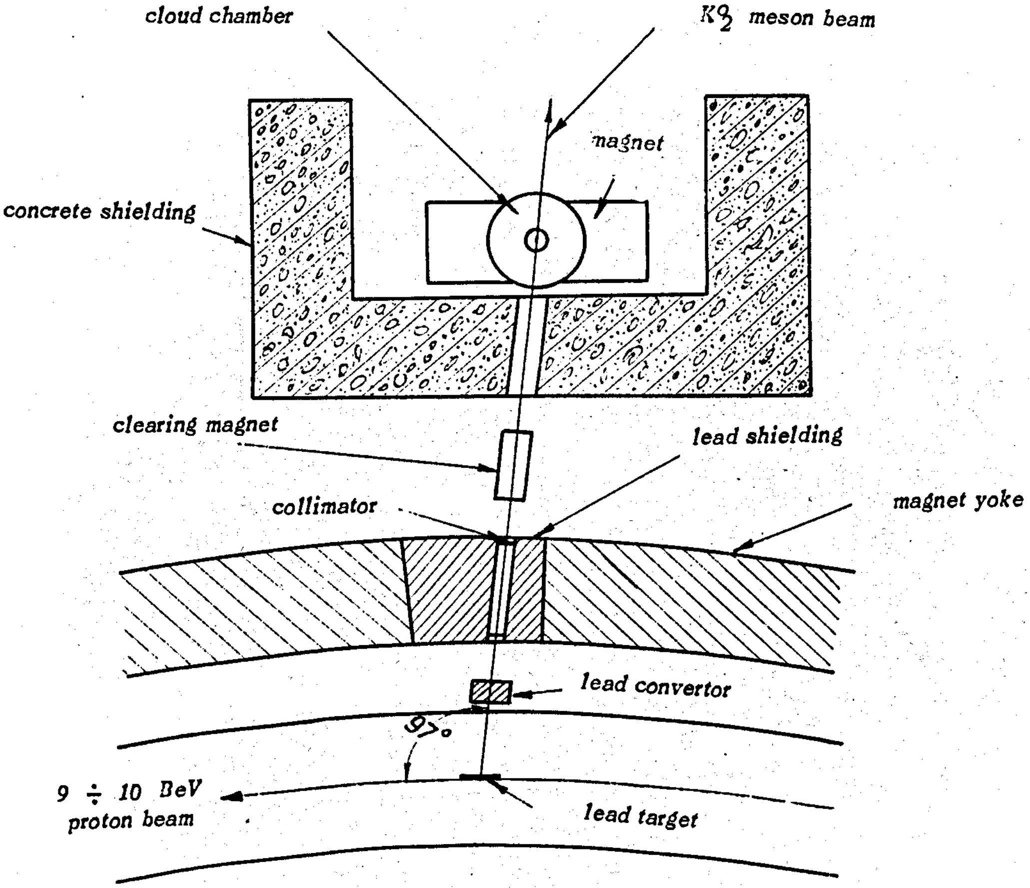
9/ The selection rule $\Delta I = ½$ with account of the phase volumes yields the magnitude of 2 for the ratio of the $K_2^0 \to 3\pi^0$ to $K_2^c \to \pi^+ + \pi^- + \pi^0$.



F i g. 1. Experimental arrangement.

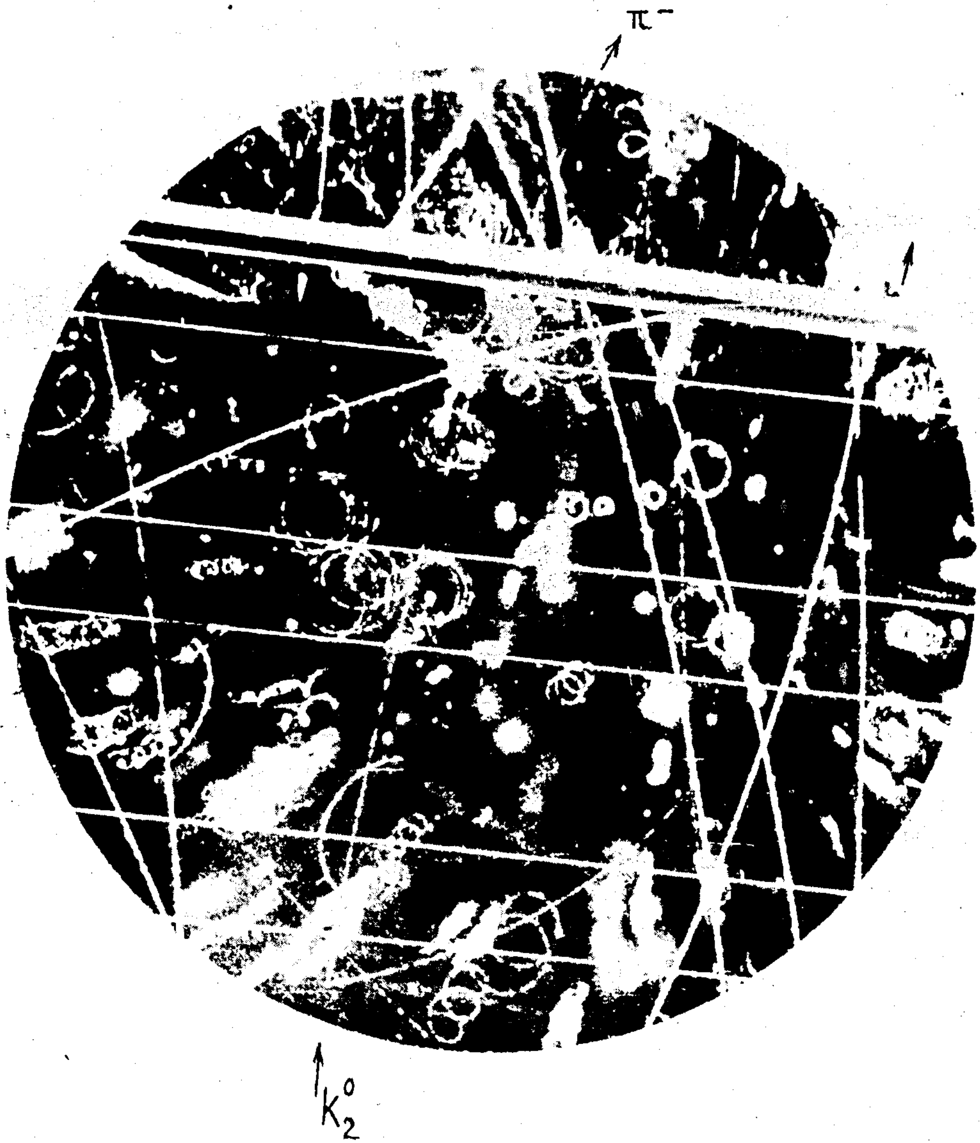


Fig. 2

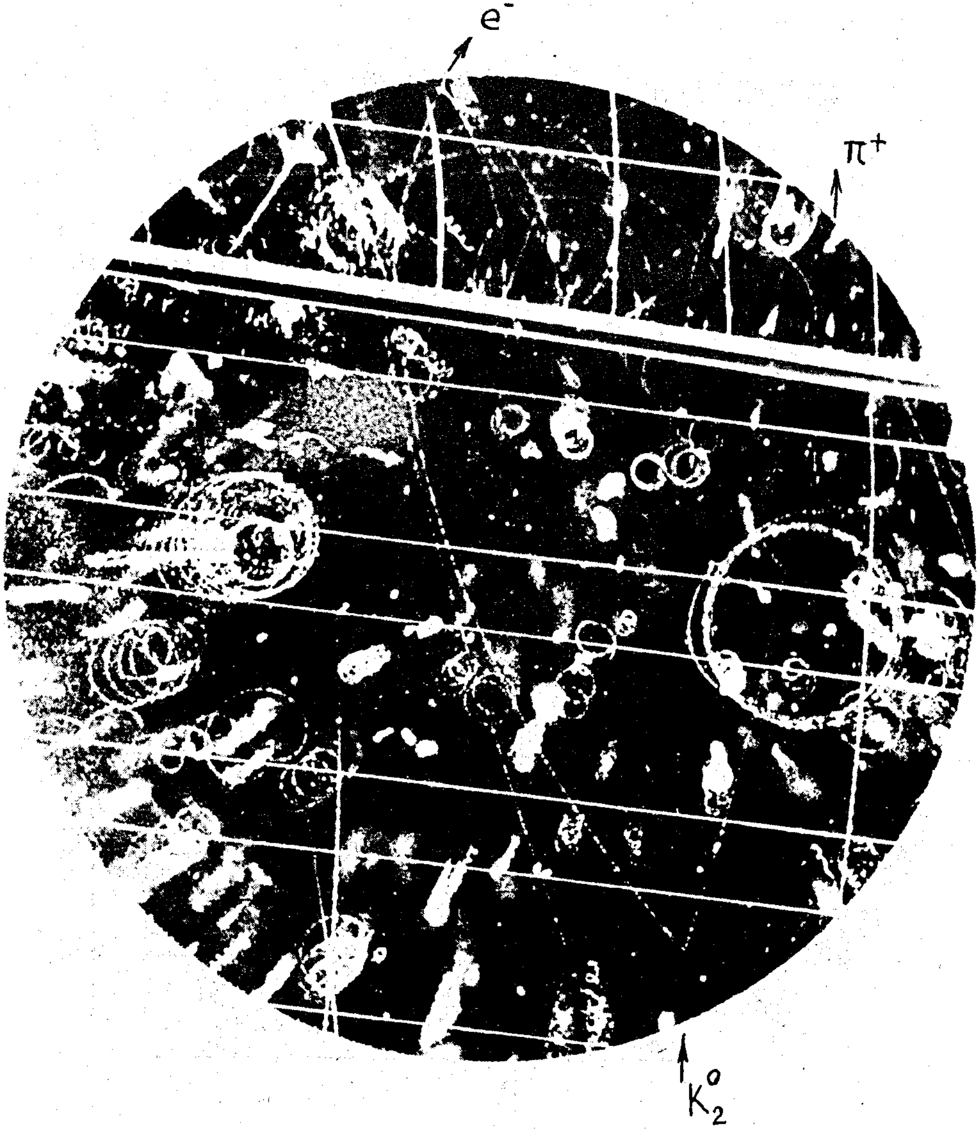
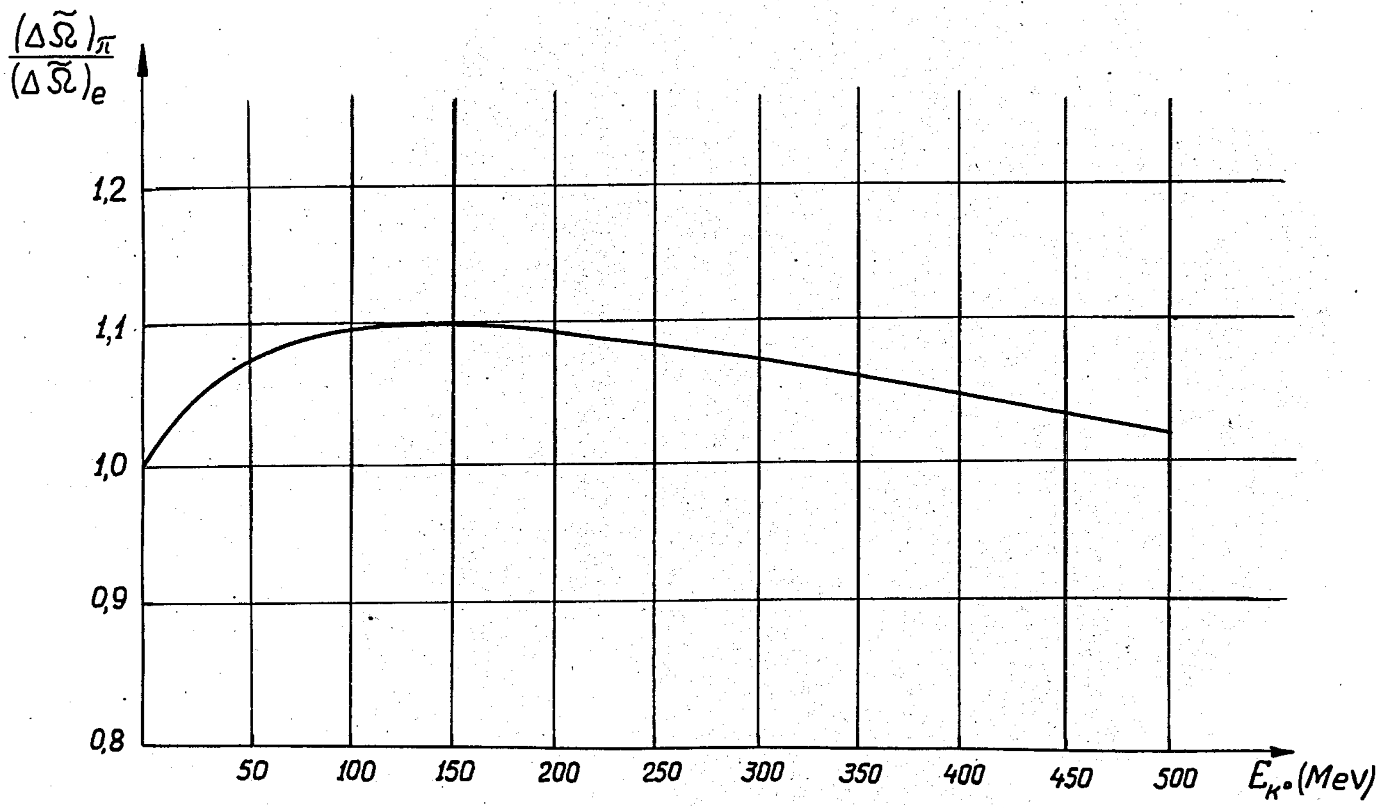


Fig. 3



F i g. 4. Geometrical correction vs. K_2^0 meson energy

Table 1.

	Momentum MeV/c		Momentum loss (in%)	Lead thickness (in g/cm2)	Momentum of a secondary (in MeV/c)
	before traversing	after traversing			
1	279	Звезда	–	6,5	148
2	209	Ост.	–	7,1	68
3	225	137 *	39	6,0	–
4	270	63 *	77	6,0	193
5	135	45 *	67	5,9	68
6	202	32	84	5,9	36
7	229	59 *	74	5,8	301
8	290	144	51	6,1	99
9	126	27*	79	5,9	248
10	310	144	54	5,8	252
11	150	9	94	8,8	–
12	189	18	90	8,8	234
13	117	22	81	6,2	158
14	283	54	81	5,9	166
15	351	225	36	7,1	99
16	193	113	41	6,3	–
17	144	77	47	5,9	410
18	113	50	56	6,2	207
19	144	Ост.	–	8,4	148
20	148	18 *	89	6,5	135
21	218	140	36	7,1	50
22	236	Ост.	Ост.	5,9	92
23	180	Ост.	Ост.	10,0	–
24	–	Ост.	Ост.	6,0	270

* shower

Table 2.

№№	Momenta MeV/c		Opening angle	Emission angle of a pair
	+	−		
1	55	42	7–9°	65°
2	10	43	99°	50°
3	111	103	19°	70°
4	26	79	25°	10°

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