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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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Abstract

The paper is concerned with the study of the production and decay of Ξ^- hyperons generated in the interaction of π^- mesons with the momenta of 6.8 $\pm$0.6 BeV/c and 8 BeV/c. 11 Ξ^- - hyperons have been obtained. The values Q= 61.9 $\pm$ 2.2 MeV, the lifetime $\tau = (3.5^{+8.4}_{-1.2})\ 10^{-10}$ sec and the production cross section for Ξ^- hyperons are given

for 6.8 BeV/c	$\sigma = (3.6^{+2.5}_{-2.1})\ \mu b$	per nucleon
for 8 BeV/c	$\sigma = (10.6^{+4.4}_{-8.2})\ \mu b$	per nucleon

The cascade hyperons have been first obtained in cosmic ray experiments. A short review of 16Ξ^- hyperons generated by cosmic rays is given by Franzinetti and Morpurgo /1/. Later on Ξ^- hyperons have been obtained with the accelerators : by 5.5 BeV/c negative pions (2 events)/2/ and by 1.15 BeV/c K^- mesons (16 events)/3/.

In our experiment a 24-litre propane bubble chamber placed in the steady magnetic field of 13700 oersted was made use of. The chamber was exposed to negative pion beams with the momenta of ~7 BeV/c and ~8 BeV/c. The experimental arrangement was already described /4/. There were scanned 27000 photographs with the momentum of primary π^-- mesons of 6.8 $\pm$0.6 BeV/c and 75000 photographs with the momentum of π^-- mesons of 8 BeV/c. The photographs were scanned twice by means of stereomagnifier and re-projectors, and a part of them was scanned for three times. In scanning we selected all the events which could be visually treated as decays of cascade particles according to the scheme $A \to V^o + B$; $V^o \to C + D$ (see, for example, Figs. 1 and 2). We selected also all secondary one prong stars from the vertex of which V^o particles emerge. Thus, 90 events have been selected . The coordinates of the corresponding points on two stereopictures have been measured with the aid of the microscopes УИМ 21The results of the measurements were analysed by an electronic computer "Ural" which gave the coordinates of the points, the momenta and the angles. In determining the errors of the particle momenta we took into account the inaccuracy in the measurements of the coordinates, the variation in the curvature of the tracks due to multiple scattering in propane and the inhomogeneity of the magnetic field in the chamber.

To identify Ξ^-- hyperons the following criteria have been used:

1) V^o must be in agreement with the kinematics of Λ^o decay into a proton and a π^-- meson;

2) the break point must lie in the V^o decay plane.

At the same time the transverse momenta of p and π^- meson from Λ^0 decay must be balanced about the line of the Λ^0 flight.

3) the decay point of Λ^0 must lie in the plane formed by the tracks of the particles A and B.

4) there must be a balance of the transverse momenta of Λ^0 and B at the break point.

5) the event must satisfy the kinematics of a Ξ^- hyperon decay : $\Xi^- \rightarrow \Lambda^0 + \pi^- + 65$ MeV.

Besides, when possible , the ionization of decay products was checked.

After the analysis, 47 events were thrown away, as V^0 had no relation to the break. 14 events satisfied criterion 2), but they were identified as K^0 . Out of 29 events satisfying criteria 1) and 2), only 15 satisfy criterion 3) ("coplanar events"). 4 of these events do not satisfy the criteria 4) and 5). Among the remaining 11 events satisfying all 5 criteria one was obtained in a π^- meson beam with the momentum ~ 6.8 BeV/c, whereas 10 in the π^- meson beam with the momentum of ~ 8 BeV/c. There are three in which V^0 agree both with Λ^0 decay and with K^0 decay within the error. The measurements of the ionization do not allow to distinguish between Λ^0 and K^0 because of large momenta of the positive particles generated in the decay. Taking into account , however, that these 3 events are in good agreement with the kinematics of Ξ^- decay, we assigned them to Ξ^- hyperons.

Table I presents the data on the identified Ξ^- hyperons. All data are obtained by averaging the results of (2 -4) fold independent measurements on the microscope.

In Table I are also given the decay energy Q and the lifetimes of Ξ^- hyperons in their own rest system.

The mean value of Q is found to be (61.9 ± 2.2) MeV for 11 events Ξ^- hyperon decay, i.e. $M_{\Xi^-} = (1317.0 \pm 2.2)$ MeV. The lifetime of Ξ^- hyperons was calculated by the maximum likelihood method and turned out to be $\tau = (3.5^{+3.4}_{-1.2})\, 10^{-10}$ sec.

After Ξ^- - hyperons have been identified the primary stars which give rise to these hyperons were analysed. With the exception of two cases (6 - 230 and 370 - 252), all the Ξ^- -hyperons are produced in the chamber. The tracks of primary stars were measured twice and the balances of momenta and energy are calculated for each star. The results are given in Table II. Six Ξ^--hyperons were produced in stars with the even number of rays and the total charge equal to 0. However, only 5 of them do not contradict π^- - p interactions (the event 171 - 218 cannot be a π^- - p interaction, since $\Delta P > \Delta E$) . If we assume for Ξ^- - hyperon S=-2, it should be expected that besides a cascades hyperon 2 K-mesons with S = +1(K^0,K^+) are generated. Only in three cases one can identify $K^{\pm}_{o}$ - meson according to the kinematics of decay. In the event 91-145 four stopped particles are identified as protons, π^{+}- meson is well identified by the momentum and the ionization, K^{+}- meson by the kinematics of decay, the seventh positive particle cannot be a $\pi^{\pm}$ meson according to the momentum and the ionization. This is either a K^{+} or a proton . In the case 19-179, under the assumption of π^{-}-p interaction , the neutral particle may be only a π^{o} -meson, then a positive particle must be a K^{+}- meson which we cannot identify by the momentum and the ionization. Thus, there was no case of the associated production of a Ξ^{-}- hyperon with two well-identified K^{+}, K^{o} mesons. At the same time there is no case which contradict such a scheme of the associated production.

Table III shows the momentum P*, the transverse momentum $P^{\perp}$, and the emergence angle Θ* of Ξ^{-} hyperons in the center-of-mass system of $\pi^{-} - N$ under the assumption that Ξ^{-}-hyperons are produced in collisions of primary π^{-}-mesons with free nucleons.

As is seen from Table III, the mean transverse momentum is equal to (318 ± 35) MeV/c. It is interesting to note , that this value of $P^{\perp}$ is close to that of the transverse momentum for protons /5/ and Λ^{o}-hyperons /6/.

Ξ^{-} hyperons are flying mainly in the backward direction just as in case for protons, Λ^{o} and $\Sigma^{\pm}$ hyperons from π^{-}p interactions at 6.8 BeV/c /8/.*

In Table III are also given the following angular characteristics:

$\Theta^{*}_{\Lambda^{o}}$ is the angle of emergence of Λ^{o} in the rest system of Ξ^{-}.

Θ^{*}_{P} is the angle of proton emergence from Λ^{o} decay in the rest system of Λ^{o}.

$\omega_{\Xi\Lambda}$ is the angle between the Λ^{o} and Ξ^{-} decay planes.

The asymmetries in the distribution of Θ^{*}_{Λ} and $\omega_{\Xi\Lambda}$ are not observed.

In the distribution of protons from Λ^{o} decay forwards-backwards (Θ^{*}_{P}) and upwards-downwards some asymmetry is observed (7- forward, 3-backward, 1 - 90° ; 8 downwards, 3 upwards). Note, that protons from Λ^{o} decay in /2/ are directed forward in the rest system of Λ^{o} . The asymmetry in the angular distributions mentioned above characterize the polarization of Λ^{o} from Ξ^{-} decay. The longitudinal polarization of Λ^{o}-hyperons from Ξ^{-} decay, if any, points out the parity nonconservation in Ξ^{-} decay.

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* It is worth while noting that both hyperons from /2/ flew in the backward direction in the c.m.s.

To determine the cross section for Ξ^- hyperon generation the number of primary π^- mesons has been calculated and the effective length of the chamber for recording Ξ^--hyperons has been determined (it turned out to be 30 + 5 cm.). We also took into account the correlations to 1) the admixture of μ^--mesons (52)% 2) the loss of a part of primary π^--mesons due to the interaction in the chamber * , 3) the efficiency of finding Ξ^-- hyperons in scanning (80 ± 10%) , 4) the geometry of the chamber (2.0 ± 0.3), 5) the neutral decay mode of Λ^0.

Thus, we have found the mean free path of π^- mesons for Ξ^--hyperon production in propane: $\ell = (20.2^{+2.86}_{-0.84}) \cdot 10^6$ cm. for the π^--meson momentum 6.8 BeV/c, $\ell = (0.68^{+0.29}_{-0.20}) \cdot 10^6$ cm for $\sim$ 8 BeV/c. If we assume the cross section for the production on the carbon nucleus to be $\sim A^{2/3}$, then for the cross section of Ξ^--hyperon production we shall have :

for 6.8 BeV/c $\qquad \sigma = (3.6^{+2.5}_{-2.1})\mu$b/N

for 8 BeV/c $\qquad \sigma = (10.6^{+4.4}_{-3.2})\mu$b/N

In [2] the cross section for the production of Ξ^- by π^- mesons with the momentum 5.5 BeV/c $\sigma = 2.3^{+3.1}_{-1.6}\mu$b/N. has been obtained. In Fig.3 the behaviour of the cross section for Ξ^--hyperon production is plotted against the energy of incident mesons** Finally, in Table IV are presented the background events among which there are four coplanar and 14 noncoplanar ones. The coplanar events can be well accounted for by the reactions indicated in Table IV. Since the reaction $\pi^- + n \rightarrow \Lambda^0 + K^-$ is forbidden according to the law of strangeness conservation, and the number of secondary K^- is less than π^+, then the major part of coplanar events is due to π^+- mesons. Noncoplanar events may be caused both by π^+ and π^-, K^--mesons. There are 7 interactions caused by π^+- mesons and 7 by negative particles. The interactions 150-286, 99-68, 1144-219 may be due only to K^-, since the energy of π^- in these events is lower than the threshold for Λ^0 production.

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* For mesons with the momentum (6 -8) BeV/c the mean free path in propane is equal to (219 ± 5) cm.

**Let us remind, that the threshold for Ξ^--hyperon production by π^--mesons in the reaction $\pi^- + p \rightarrow \Xi^- + K^+ + K^0$ is equal to $(2.19^{+0.61}_{-0.43})$ BeV [7] if we take into account the nucleon motion in a nucleus.

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Table 1. Data on identified Ξ^- hyperons.

P_{π^-} (Bev/c)	The number of the event	P_{Ξ^-} * (MeV/c)	P_Λ (MeV/c)	P_{π^-} (MeV/c)	$\Theta_{\Xi^-\Lambda^0}$	$\Theta_{\Xi^-\pi^-}$	$\Delta P^\perp$ ** (MeV/c)	noncoplanar angle η ***	Q_{Ξ^-} (MeV)	t (10^{-10} sec.)
7	182-42	3517±420	3166±415	374±67	2°54'±30'	18°30'±30'	41±42	9'	63,4±14,4	1,13±0,11
8	91-145	1894±150	1507±150	406±48	4°7'±40'	15°25'±40'	1±25	14'	55,7±13,7	2,53±0,11
8	196-160	1247±185	963±180	317±44	6°45'±30'	23°11'±30'	12±28	18'	69,1±18,5	3,37±0,27
8	19-179	2811±490	2407±490	445±64	4°9'±30'	18°43'±30'	31±46	20'	73,2±16,5	0,93±0,11
8	171-218	1398±235	1181±230	263±29	6°22'±1°20'	31°36'±30'	8±38	47'	64,4±11,0	3,29±0,37
8	6-230	2008±190	1583±185	438±39	2°58'±1°	13°2'±50'	17±29	1°4'	52,5±11,5	>1,9
8	370-252	878±155	753±151	197±39	10°1'±40'	46°20'±30'	11±39	2'	67,5±20,3	>6,4
8	114-290	751±93	625±94	196±19	13°1'± 27'	43°27'±27'	6±30	3° ****	63,4± 9,5	2,79±0,41
8	355-298	1812±227	1593±223	253±44	4°58'±1°30'	27°25'±30'	21±51	58'	53,2±17,3	0,61±0,09
8	150-307	2440±307	2098±305	372±45	5°1'±1°	19°42'±40'	58±48	1°26'	56,2±15,3	0,46±0,07
8	186-336	982±115	702±106	315±51	8°35'±30'	24°4'±30'	23±27	24'	86 ±26	0,77±0,14
mean values		1794							61,9±2,2	2,20

* Since some tracks were short, not all could have been obtained directly from measurements, given P_{Ξ^-} have been calculated by the formula $P_{\Xi^-} = P_\Lambda \cos\theta_{\Xi\Lambda} + P_\pi \cos\theta_{\Xi\pi}$

** $\Delta P^\perp = \left| P_\Lambda \sin\theta_{\Lambda\Xi} - P_\pi \sin\theta_{\Xi\pi} \right|$

*** η - angle between the primary particle of a one-prong star and the plane formed by Λ^0 and the secondary particle, the error in the determination of angle η is $1^\circ 30'$

**** A large error because of the difficulties in the measurements.

Table II. Data on primary stars accompanied by the Ξ^- production

P_{π^-} (GeV/c)	№ case	star	other identified strange particles	$\sqrt{(\Delta E)^2 - (\Delta p)^2}$ * (MeV)	A possible reaction
7	I82–42	two-prong (I+, I-)		I826±2I0	$\pi^- + p \to \Xi^- + \pi^+ + (K^0 + K^0 + \ldots)$ **
8	9I–I45	ten-prong (7+, 2-иI?)	K^+ stops and decays	394 $^{+I50}_{-270}$	$\pi^- + C \to \Xi^- + K^+ + (K^-) + \pi^+ + \pi^- + 4p + \ldots$
8	I96–I60	two-prong (I+, I-)		I880±I80	$\pi^- + p \to \Xi^- + \pi^+ + (K^0 + K^0 + \ldots)$
8	I9–I79	six-prong (3+, 3-)	K^+ stops and decays	I85 $^{+I00}_{-I40}$	$\pi^- + p \to \Xi^- + K^+ + (K^-) + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^0$
8	I7I–2I8	four-prong (2+, 2-)		$\Delta P > \Delta E$	$\pi^- + C \to \Xi^-$ + other particles
8	II4–290	five-prong (4+, I-)	K^0 decays	$\Delta P > \Delta E$	$\pi^- + C \nearrow \Xi^- + \pi^+ + \pi^+ + K^0 + (K^0 + \ldots) + 2p$ $\searrow \Xi^- + K^0 + (K^+) + \pi^+ + 2p + \ldots$
8	355–298	three-prong (I+, 2-)		~ II00	$\pi^- + n \nearrow \Xi^- + \pi^- + \pi^+ + (K^0 + K^0)$ $\searrow \Xi^- + \pi^- + (K^+ + K^0 + \ldots)$
8	I50–307	two-prong (I+, I-)		~2I00	$\pi^- + p \nearrow \Xi^- + \pi^+ + (K^0 + K^0 + \ldots)$ $\searrow \Xi^- + (K^+ + K^0 + \ldots)$
8	I86–336	two-prong (1+, I-)		~I520	$\pi^- + p \to \Xi^- + \pi^+ + (K^0 + K^0 + \ldots)$

* ΔE was calculated under the assumption that there takes place the interaction of a π^- - meson with a free nucleon.

** supposed particles are indicated in brackets.

Table III.

P_{π^-} (BeV/c)	The number of the event	$P^*_{\Xi^-}$ (in the c.m.s.) (MeV/c)	$P^{\perp}_{\Xi^-}$ (MeV/c)	$\theta^{*\circ}_{\Xi^-}$ (in the c.m.s. πN)	$\theta^{*\circ}_{\Lambda^\circ}$ (in the c.m.s. Ξ^-)	$\theta^{*\circ}_{p}$ (in the c.m.s. Λ°)	The angle between the planes Λ° and Ξ^- decay $\omega^\circ_{\Xi\Lambda}$	The direction of p emergence with respect to the plane of decay of Ξ^-
7	I82-42	558±62	375±48	$42^0\pm II^0$	7I±5	92±5	I46±5	downwards
8	9I-I45	4I4±47	I45±26	$I59^\circ\pm 4^\circ$	I22±5	42±5	I3I±4	upwards
8	I96-I60	I00I±99	290±30	$I62^0\pm 3$	I23±5	67±6	52±3	downwards
8	I9-I79	294±4I	293±4I	$94^0\pm II$	88±I0	73±5	I6I±5	downwards
8	I7I-2I8	977±I07	4I0±47	I55± 4	94±5	50±7	87±4	downwards
8	6-230				I32±8	75±5	I00±6	upwards
8	370-252				9I±I0	I30±5	23±5	upwards
8	II4-290	I538±II0	273±36	I70±3	I02±5	I05±5	I68±6	downwards
8	355-298	I070±I02	729±92	I37±6	73±5	35±I0	82±4	downwards
8	I50-307	$I40\ ^{+I45}_{-64}$	7I±3I	$I49^{+22}_{-86}$	75±I5	70±I5	88±8	downwards
8	I86-336	I248± I0	273±36	I67±4	I26±4	I02±5	66±4	downwards
mean values		804	3I8±35					

Table IV.

background events (V^0 particles were identified as Λ° particles).

	The number of event	sign	the noncoplanarity angle η	$\Delta p^\perp$ MeV/c	One of possible interactions
I	344-3I4	+	I′	225	$\pi^+ + n \to \Lambda^0 + K^+$
2	250-35	+	I6′	200	$\pi^+ + n \to \Lambda^0 + K^+$
3	267-233	+	I^0I9'	48	$\pi^+ + n \to \Lambda^0 + K^+$
4	I50-286	-	22′	I26	$K^- + n \to \Lambda^0 + \pi^-$
5	502-I2	+	$2^039'$	56	$\pi^+ + n \to \Lambda^0 + K^+$
6	I85-9I	+	$4^056'$	58	$\pi^+ + n \to \Lambda^0 + \pi^+ + (K^0)$
7	52-246	+	$4^057'$	I6	$\pi^+ + n \to \Lambda^0 + K^+$
8	I89-275	+	$5^054'$	I7	$\pi^+ + n \to \Lambda^0 + K^+$
9	33-22I	+	$8^053'$	497	$\pi^+ + c \to \Lambda^0 + P + (K^0) + \ldots$
I0	273-I25	+	$I0^0I0'$	827	$\pi^+ + n \to \Lambda^0 + (+?) + \ldots$
II	I40-45	+	$22^042'$	244	$\pi^+ + n \to \Lambda^0 + \pi^+ + (K^0) + \ldots$ **
I2	99-68	-	$3^036'$	86	$K^- + n \to \Lambda^0 + \pi^-$
I3	I79-22I	-	$4^027'$	I25	$\pi^- + n \to \Lambda^0 + \pi^- + \ldots$ *
I4	I44-2I9	-	$7^04'$	I06	$K^- + n \to \Lambda^0 + \pi^- + \ldots$
I5	I52-I88	-	$I6^040'$	59	$\pi^- + n \to \Lambda^0 + \pi^- + \ldots$ *
I6	64-69	-	$I7^030'$	70	$\pi^- + n \to \Lambda^0 + \pi^- + \ldots$ *
I7	6I-I74	-	30^0		$\pi^- + n \to \Lambda^0 + \pi^- + (K^0$
I8	288-I93	-	40^0	50	$\pi^- + n \to \Lambda^0 + \pi^- + \ldots$ *

* (K^-n) *interaction is possible*

** *In this case another reaction with the generation of Λ° is also possible. We have pointed out the most probable one.*

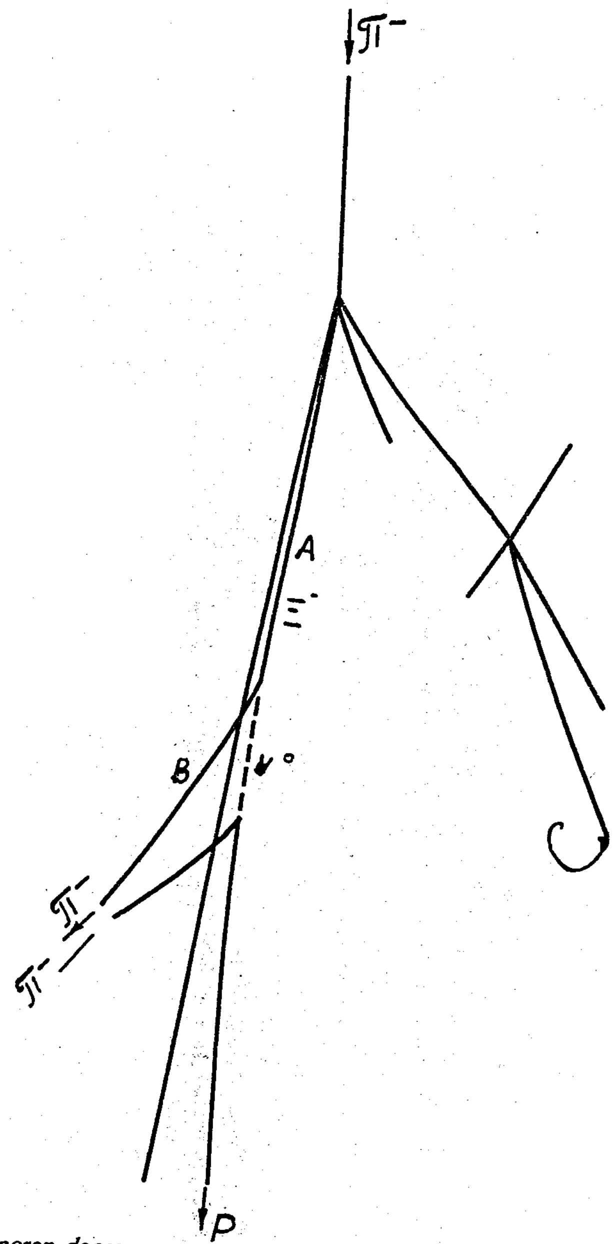

Fig. 1. Event 171-218 . Ξ^- Hyperon decay

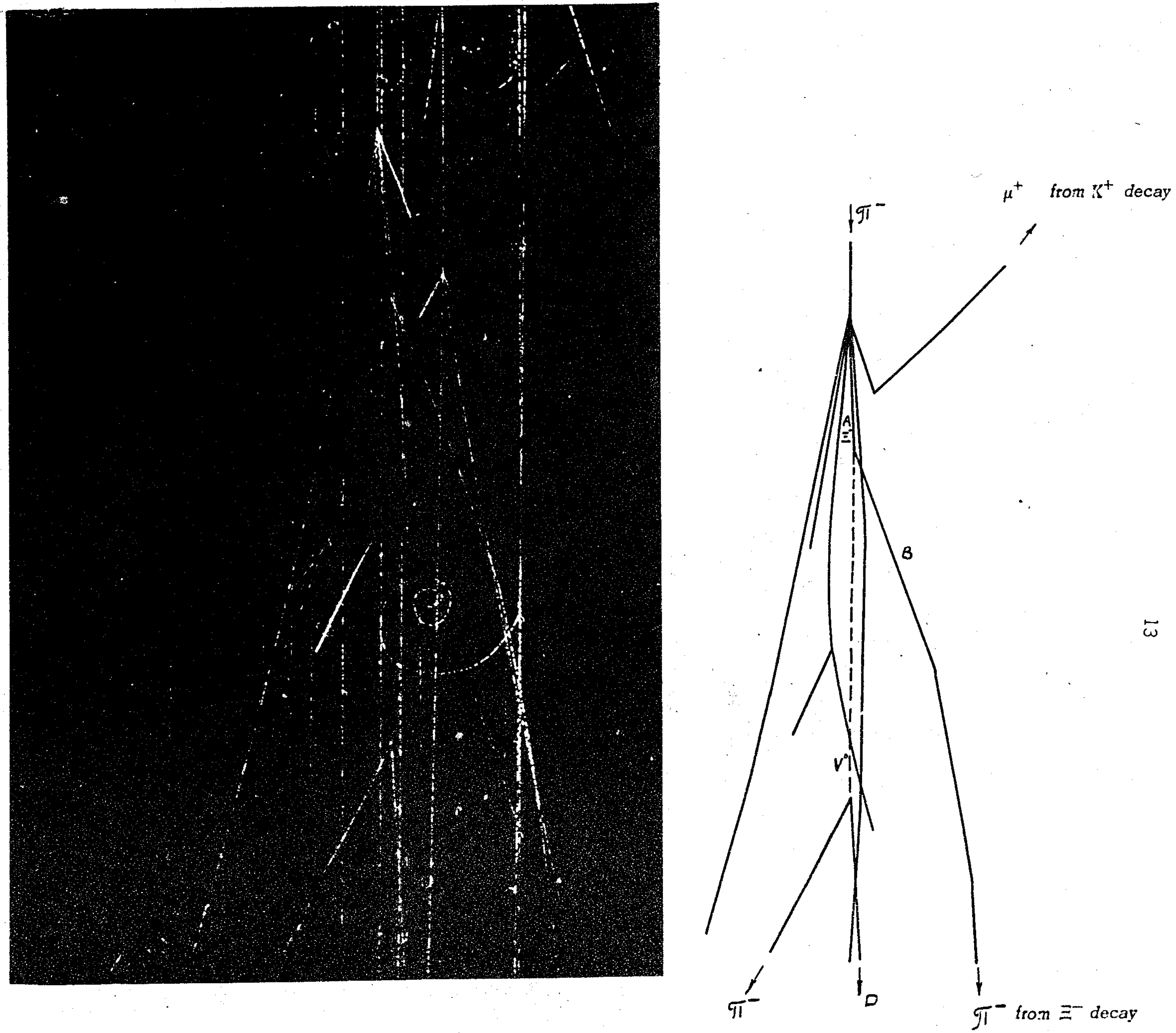

Fig. 2. Event 19-179. Ξ^- *Hyperon decay*

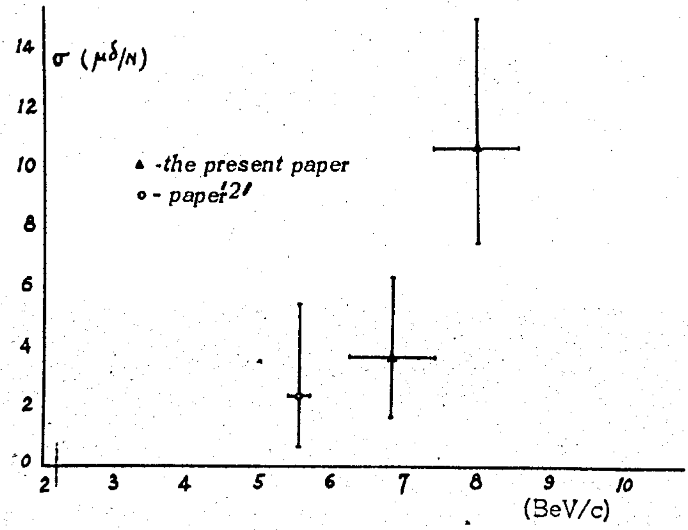

Fig. 3 Ξ^- *hyperon production cross section vs incident* π^- *meson energy.*