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On the X-particles Observed in the Cosmic Ray Jet Showers

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Summary of X particles observed so far in the emulsion chambers exposed to cosmic rays at aeroplane and balloon altitudes are presented. Most of the cases, were observed associated production of the X particles possibly bearing new kind of quantum number. The mass, the mean life time and the production rate of these particles are discussed on the present statistics.

In the year 1971, a possible new particle[1] was observed among the secondary particles of jet showers induced by super high energy cosmic rays. Figure 1. shows the three dimensional projections of central part of the jet shower with a type of (19+70)n in which the new particle was produced. The most impressive features of the event were sudden changes of flight directions of two charged particles, B and C at 1.38 cm and 4.88 cm respectively from the origin O, and the coplanarity relation among tracks OB, BB' and that of π^0 meson. Assuming a two body decay of a 'X±' particle into a π^0 meson and a charged hadron, mass and life time of the parent particle was estimated as 1.5∿3.5 GeV and $0.2 \sim 0.4 \times 10^{-13}$ second under different assumptions as to the nature of the charged daughter. Mass, life time and transverse momentum of daughter particles suggested us that our X particle could be neither strange particle nor resonance particle. If the direction change of the track C was also attributed to a decay of particle C into a charged and other neutral hadronic particles, the event might be an associated production of new type of particles.

Just after the discovery of this event, S.Ogawa and his collaborators[2] reached a conclusion that the X particle might be a new kind of hadron bearing a further attribute beyond isotopic spin and strangeness, called p' charge or charm (c), and might be produced in a pair by the strong interaction but each decaying into ordinary hadrons via weak interaction with life time of several times 10^{-13} second. Being stimulated by the theoretical work done by the Hiroshima group and others, systematic studies of super high energy jet showers and hunting of X particles have been continued exposing emulsion chambers specially designed for the purpose at balloon and aeroplane altitudes. Further evidences have been accumulated from our own exposures and also from reanalysis of certain anomalous events published by others[3]. Another remarkable event which

cleary showed a pair production of particles with similar characteristics to those found or analysed by us was observed last year by H.Sugimoto et al[4]. In this paper, a summary of these cosmic ray events is given with some discussions.

Our emulsion chamber now using in the cosmic ray experiments consists of two parts as is shown in the Figure 2. The upper part is a pile of nuclear emulsion plates coated on both surface of plastic base of 800 μm thick and some amounts of spacers. Nuclear interaction mean free path and unit cascade length in this part is about 100 cm and 50 cm respectively. This is very effective to minimize the disturbance due to cascade showers of produced particles. It is possible to observe cross sectional view of the secondary tracks each 1 mm along the shower axis in this pile, the thickness of which is 14 cm. Special care taken to assemble the chamber enabled us in favorable cases to measure the relative angles among tracks of charged particles with error less than 10^{-5} radian.

The lower part is a sandwich of 50 lead plates with thickness of 1 mm and the same number of nuclear emulsion plates. Total thickness of this part is 10 cm, and this corresponds to 10 cascade units. It works not only as a detector and analyser for γ rays, but also as an analyser of charged secondary particles. Following tracks of charged secondary particles down to the bottom of the chamber we can discriminate electrons from other components. Moreover, applying the relative scattering method on these tracks in the lead emulsion sandwich, we are now able to measure momenta of charged particles in TeV/c region. This method was calibrated at 205 and 303 GeV/c[5] exposing similar type of emulsion chambers to the

proton beams at the Fermi National Accelerator Laboratory. Success of application of the relative scattering method to the TeV/c region, added a power to our type of emulsion chamber.

Table I is the event list so far picked up from our own exposures as well as digged out of reanalysis of certain events published by others. The first event labelled 6B-23 and the event named 11c-34[6] are from our own exposures, and the events T, ST-2 and Bo-607 are the reanalysed ones.

Figures 3 show essential features of these events. Among them T star was observed by the Rochester Group[3] about 25 years ago in their first experiment applying emulsion cloud chamber to the study of supper high energy phenomena. The Jet shower ST-2[3] was observed also in the first balloon experiment of the Japanese Emulsion Chamber Group in 1956, and the event Bo-607[3] is one of high energy jet showers observed by the Bristol Bombay Group in tungsten emulsion chamber exposed to cosmic rays by balloon in 1961. It is exceedingly impressive that since old days they have already observed such events very similar to ours by means of the emulsion chamber type of detectors.

All of the events listed in the Table I are induced by primary particles with energy of 10∿25 TeV and characterized by relatively high n_s value in comparison with the mean value at this energy region and by so called torpedo type feature in which very high percentage of liberated energy to soft components is concentrated on a single or double π^0 mesons. In most of the events associated production of new kind of particles are observed and in one of jet showers probably we have observed a new kind

of cascade decay.

Last year another Japanese Group[4] have observed an event in a balloon flight at an altitude of 10 gr/cm^2 which has very similar characteristics to our events clearly showing a pair production of X particles.

In the Table II, X particles observed so far are classified according to thier assumed decay modes. The charge neutral ratio of observed X particles is 10:6 including detection biases.

About the mass of X particles, only samples of type I in the Table II are available. Assuming the charged daughter of X particle is K meson, mean value of 1.85±0.4 GeV is calculated from 3 samples.

As for the mean life time of X particles, the distribution shown in the Figure 4 was got assuming mass value as 2 GeV. It seems unlikely to fit them with simgle exponent. Dividing those samples into two groups, charged and neutral ones, the mean life time of charged X particles turned out to be $\sim 2\times 10^{-12}$ second and that of neutral ones to be $\sim 4\times 10^{-13}$ second.

For about the production rate of X particles in the cosmic ray region, it is difficult to estimate it accurately, because of the detection biases. The rate of 1 event per 20$\sim$40 observed jet showers of 10 TeV region is, however, roughly estimated in our case. Taking detection biases into account this rate should be lowered by factor 2 or 3.

Possible candidates of X particle were also found in our emulsion chambers exposed to 205 GeV/c proton beams at the Fermi National Accelerator Laboratory[7]. One is neutral and the other is charged one. The neutral one is the first example of X particle which decayed into two charged hadrons. Mass and life time of these particles are similar as those from cosmic ray experiments. The production cross section of X particles in

the accelerator energy region is roughly estimated to be between 10^{-2} and 10^{-3} of total inelastic cross section on our present statistics and this is about one order lower than that observed at the cosmic ray energy ($\sim$10 TeV) region.

Recently, there have been a remarkable number of important discoveries indicating the new degree of freedom of elementary particles: the J or ψ, ψ' and possible ψ'' states discovered at BNL and SLAC, sudden rise of $R \equiv \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ at $\sqrt{s} \simeq 3.1$ GeV and further structure in R for $\sqrt{s} > 4$ GeV observed at SLAC, $\mu^+\mu^-$ events in FNAL neutrino experiment, the appearance of extra leptons at high p_T observed at FNAL and ISR, the apparent $\Delta s/\Delta Q = -1$ process observed in neutrino interactions at BNL.

Quartet scheme[8] introducing fourth urbaryon, p' — charmed quark, c, seems to be promising to explain unifyingly X-particles and these experimental results[9]. But it is required not only to accumultate more statistics of X-particles and to study their nature more precisely but also to investigate internal relation between X-particles and these new phenomena comprehensively.

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Captions of Tables and Figures.

Table I. Event List.

Table II. Classification of X particles observed.

Fig. 1. Event 6B-23.

Fig. 2. The Emulsion Chamber. ($25\times20\times24$ cm^3)

Fig. 3-a. Interpretation of the T star.

Fig. 3-b. Event ST-2.

Fig. 3-c. Sketch of the Event Bo-607 reanalysed by us. (Professors B.V.Sreekantan and P.K.Malhotra kindly lended us emulsion plates.)

Fig. 3-d. Event 11c-34.

Fig. 4. Distribution of Life Time of X particles.

Table I

	ch. of lry ptl.	E (TeV)	n_s	$\Sigma E\gamma$ (TeV)	$E\pi^0$ or γ (TeV)
6B-23	0	10	70	4.5	3.2
T	1	20	36	6	2.4, 1.6
ST-2	?	25	51	2.1	1.0
11c-34	0	20	70	8	3.0, 0.6, 1.2
Bo-607	?		?	2.7	2.0
			(High n_s)	(Torpedo type)	

Table II

	I	II	III	IV	V	VI
Charge		X			X	
Decay	2 body n.+(c.)	? (n.)+(c.)	$\geqq$3 body n.+(n.)+(c.)	2 body (c.)+(c.)	? n.+(n.)	$\geqq$3 body (n.)+(c.)+(c.)
6B-23	π^0+x					
		$x^0+x^\pm$				
11c-34		$x^0+x^\pm$				
		$x^0+x^\pm$				
					π^0+x^0	
					π^0+x^0	
			$\gamma+x^0+x^\pm$			
		$x^0+x^\pm$				
		$x^0+x^\pm$				
BEC II*	$\eta^0+x^\pm$					
	$\pi^0+x^\pm$					
T					π^0+x^0	
					π^0+x^0	
ST-2					π^0+x^0	
			$\eta^0+x^0+x^\pm$			
Bo-607					π^0+x^0	
No.	3	5	2			
Obs.	10			0	6	0

* Reference 4)

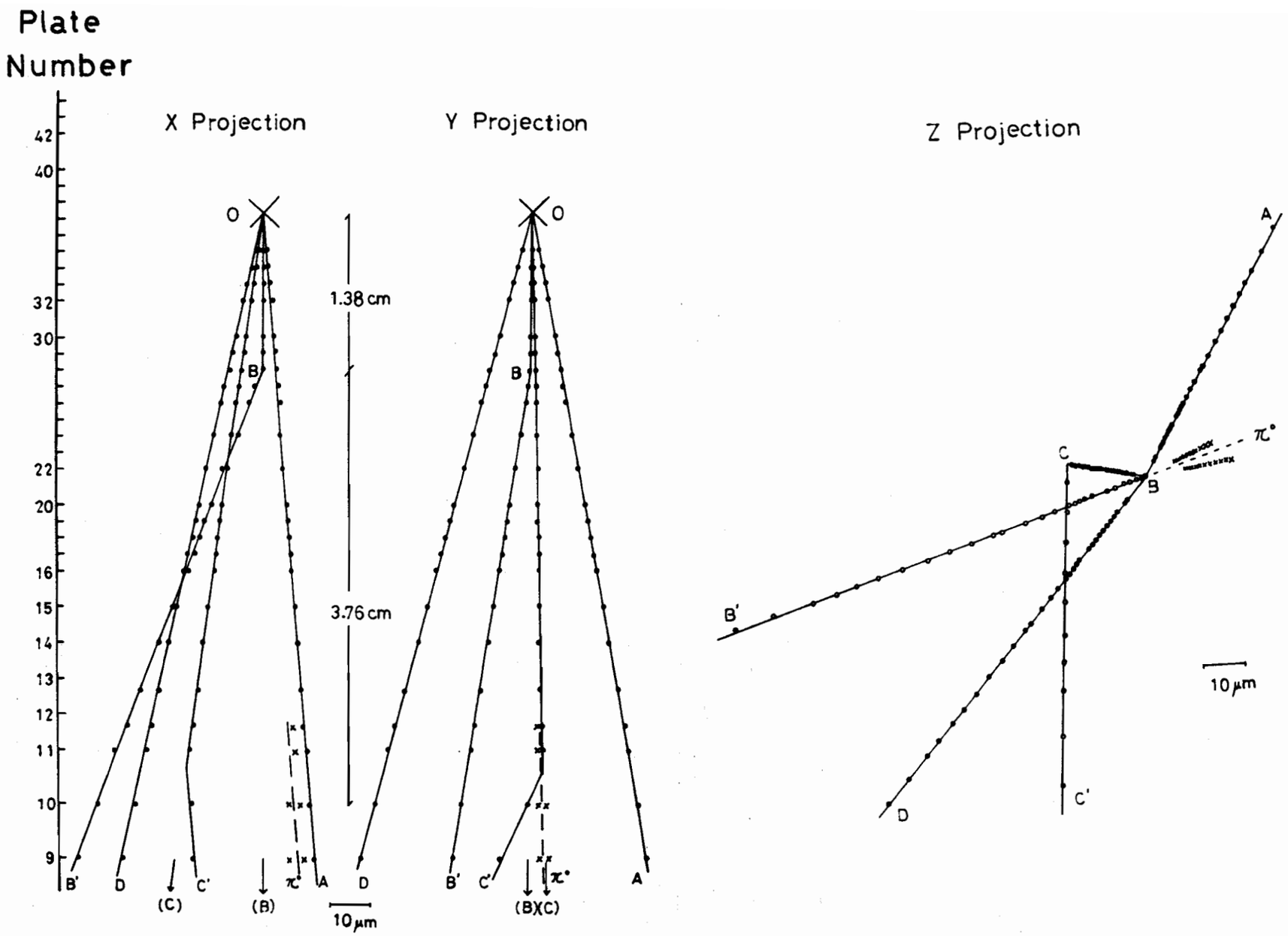
Plate Number
X Projection
Y Projection
Z Projection
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40
32
30
22
20
16
15
14
13
12
11
10
9
O
B
1.38 cm
3.76 cm
B'
D
C'
(C)
(B)
π°
A
10 μm
(B)(C)
C
π°
B'
D
C'
10 μm

Fig. 1

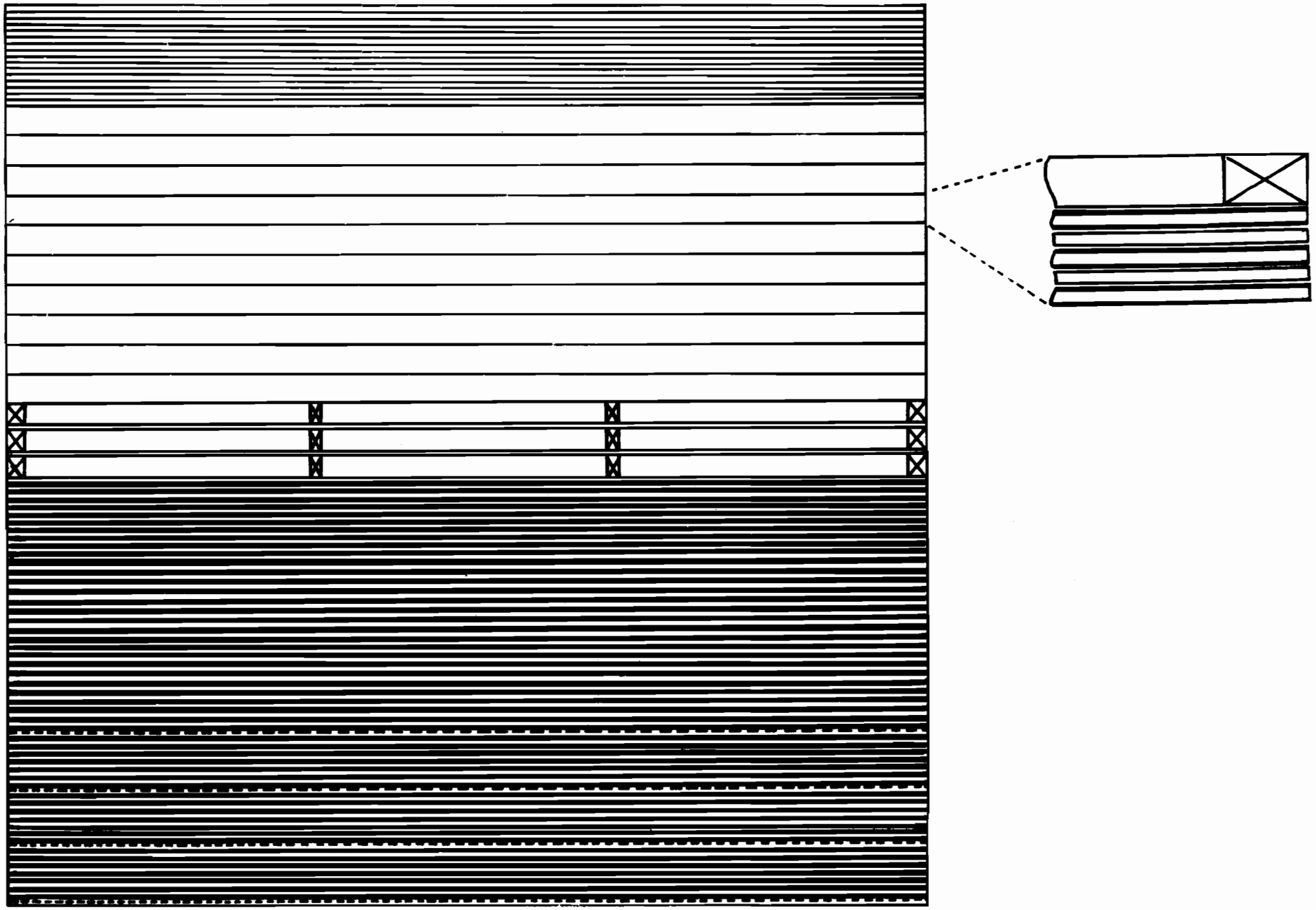


Fig. 2

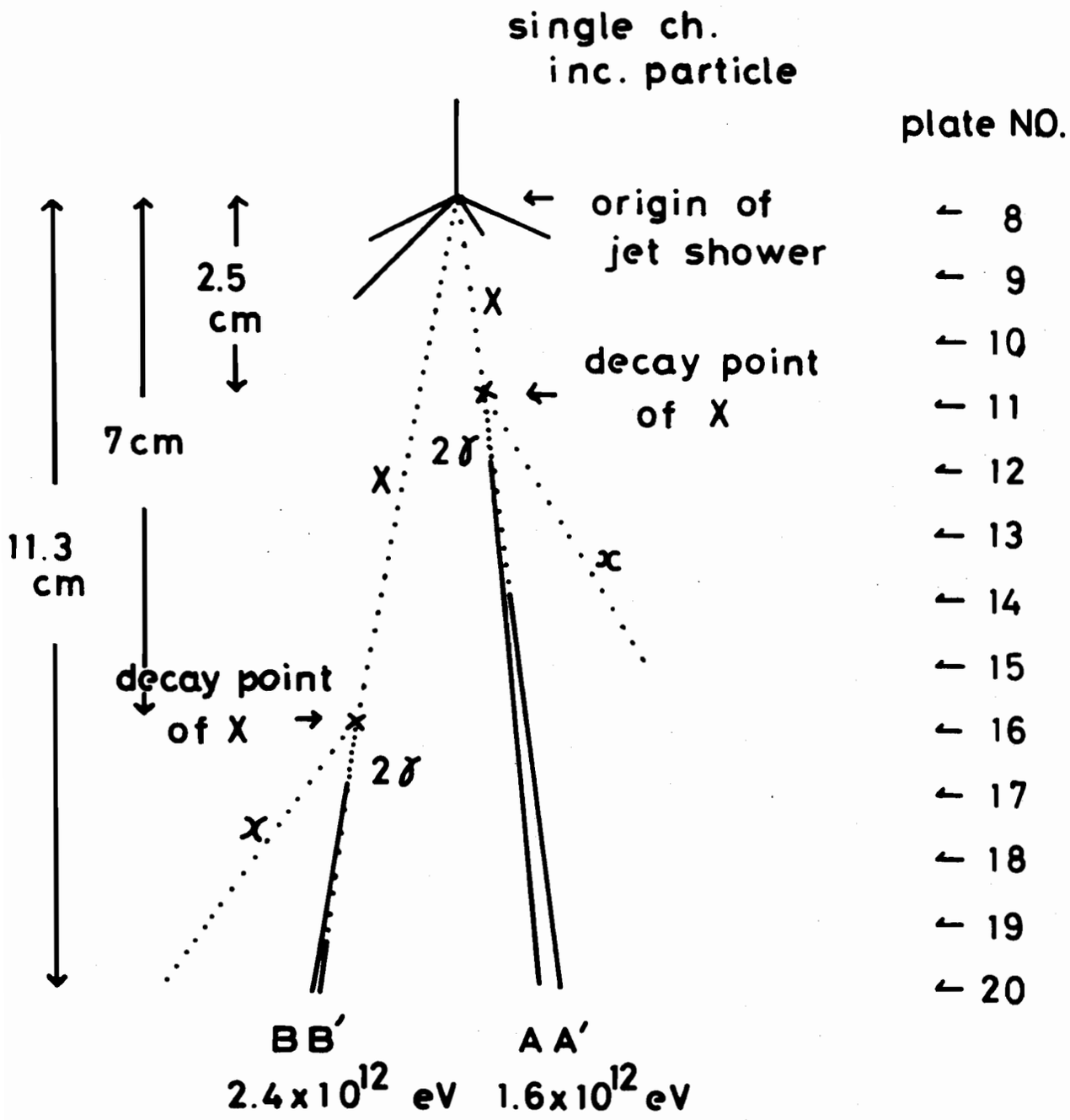

single ch.
inc. particle
plate NO.
origin of
jet shower
8
9
10
11
12
13
14
15
16
17
18
19
20
2.5
cm
7cm
11.3
cm
X
decay point
of X
2γ
X
x
decay point
of X
2γ
x
BB′
2.4x10^12 eV
AA′
1.6x10^12 eV

Fig. 3-a

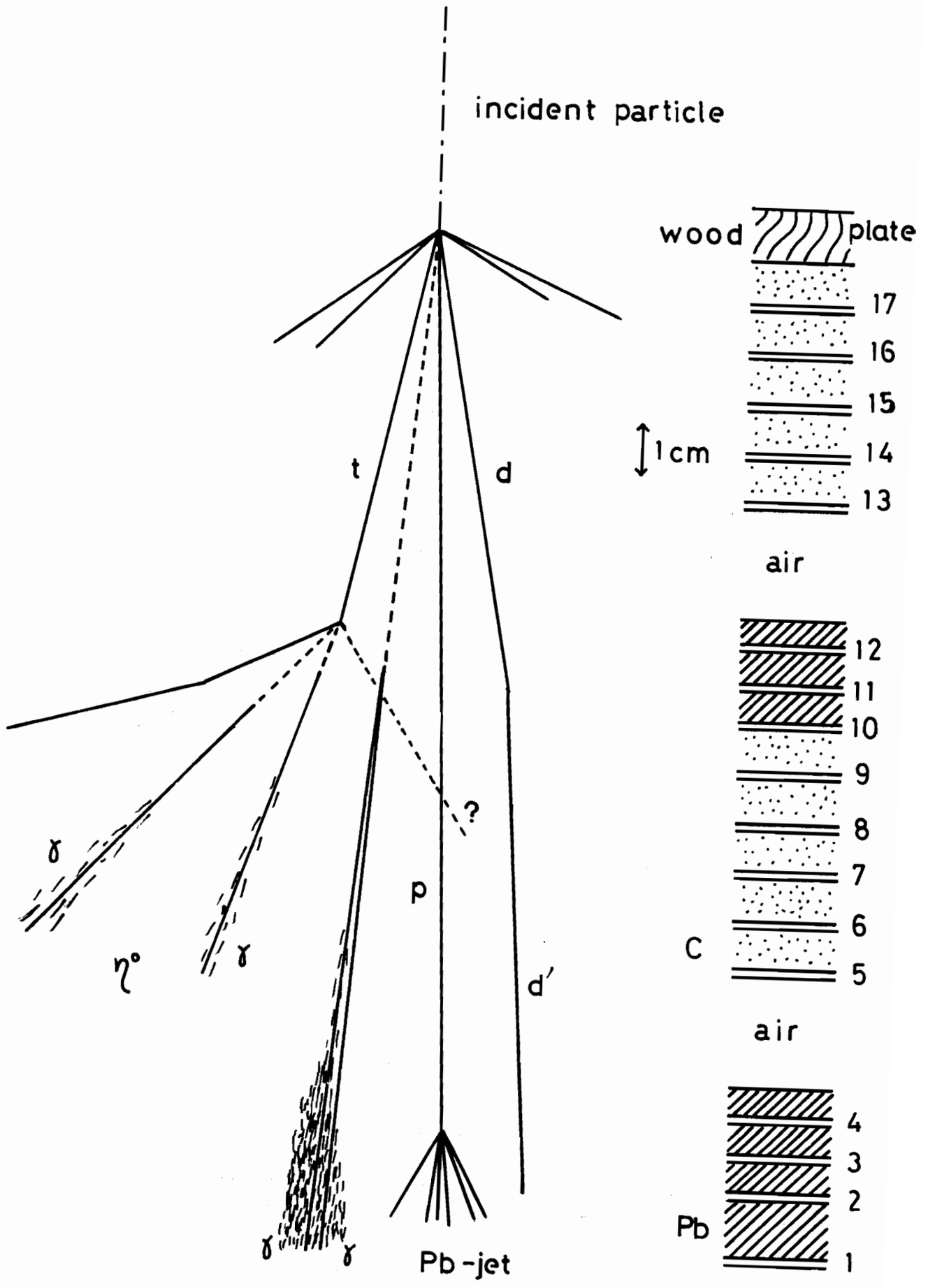

incident particle
wood
plate
17
16
15
1cm
14
13
air
t
d
12
11
10
9
8
7
6
C
5
air
?
γ
p
η°
γ
d'
4
3
2
Pb
1
γ
γ
Pb-jet

Fig. 3-b

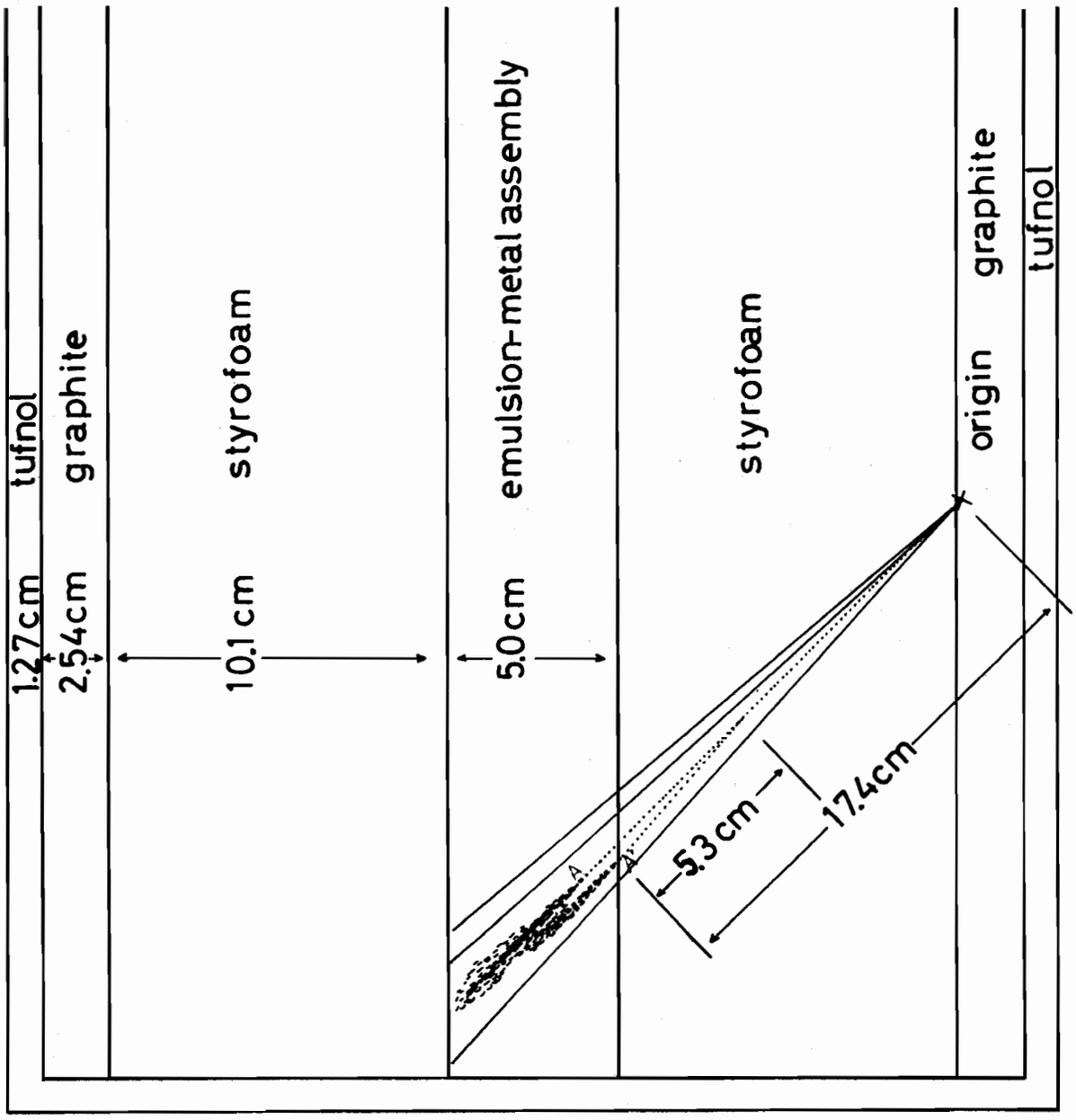
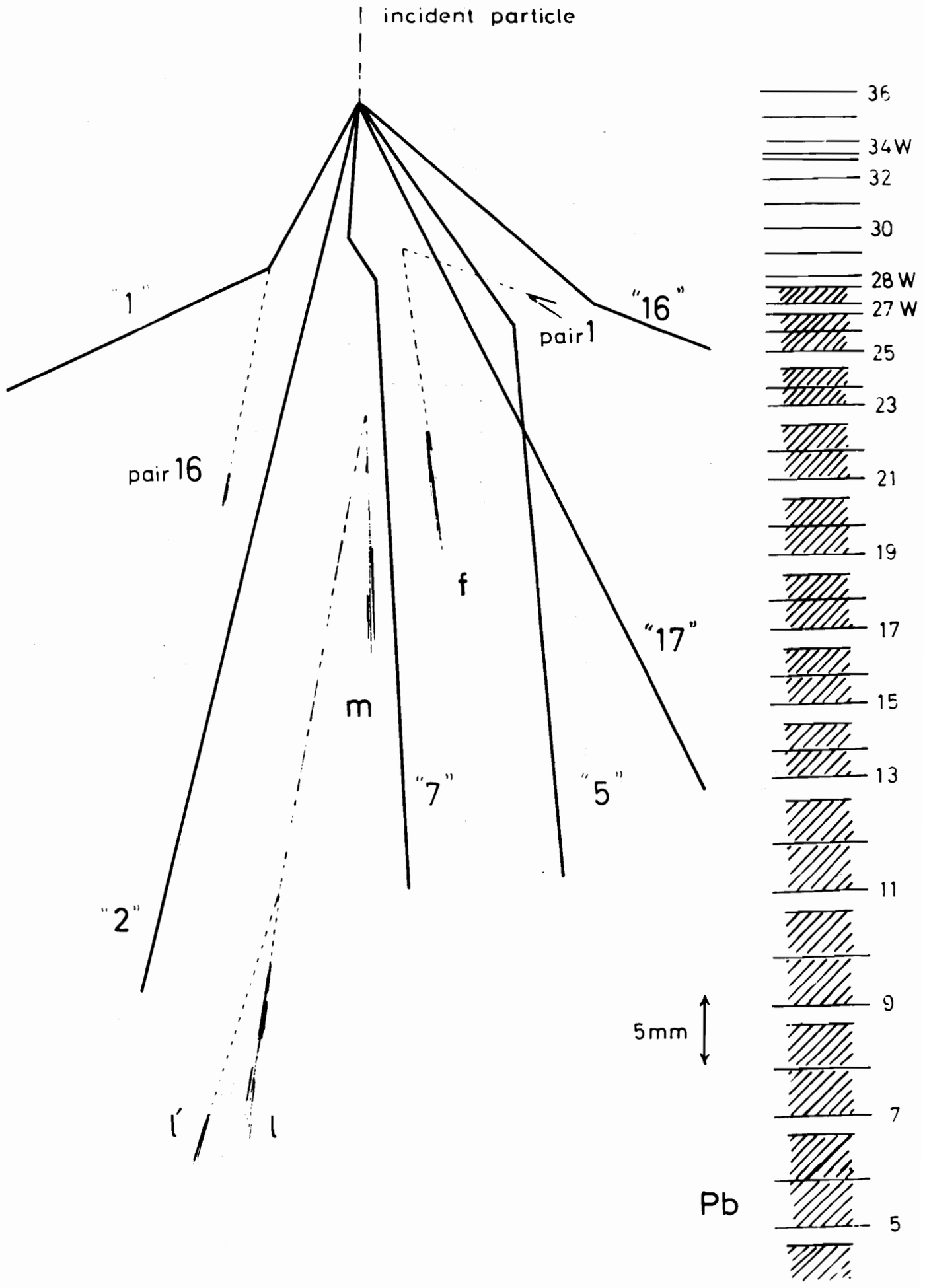

tufnol
1.27cm
graphite
2.54cm
styrofoam
10.1 cm
emulsion-metal assembly
5.0cm
styrofoam
A
5.3 cm
17.4cm
origin
graphite
tufnol

Fig. 3 - c


incident particle
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"16"
pair 1
pair 16
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m
"17"
"7"
"5"
"2"
5mm
Pb
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34 W
32
30
28 W
27 W
25
23
21
19
17
15
13
11
9
7
5

Fig. 3 - d

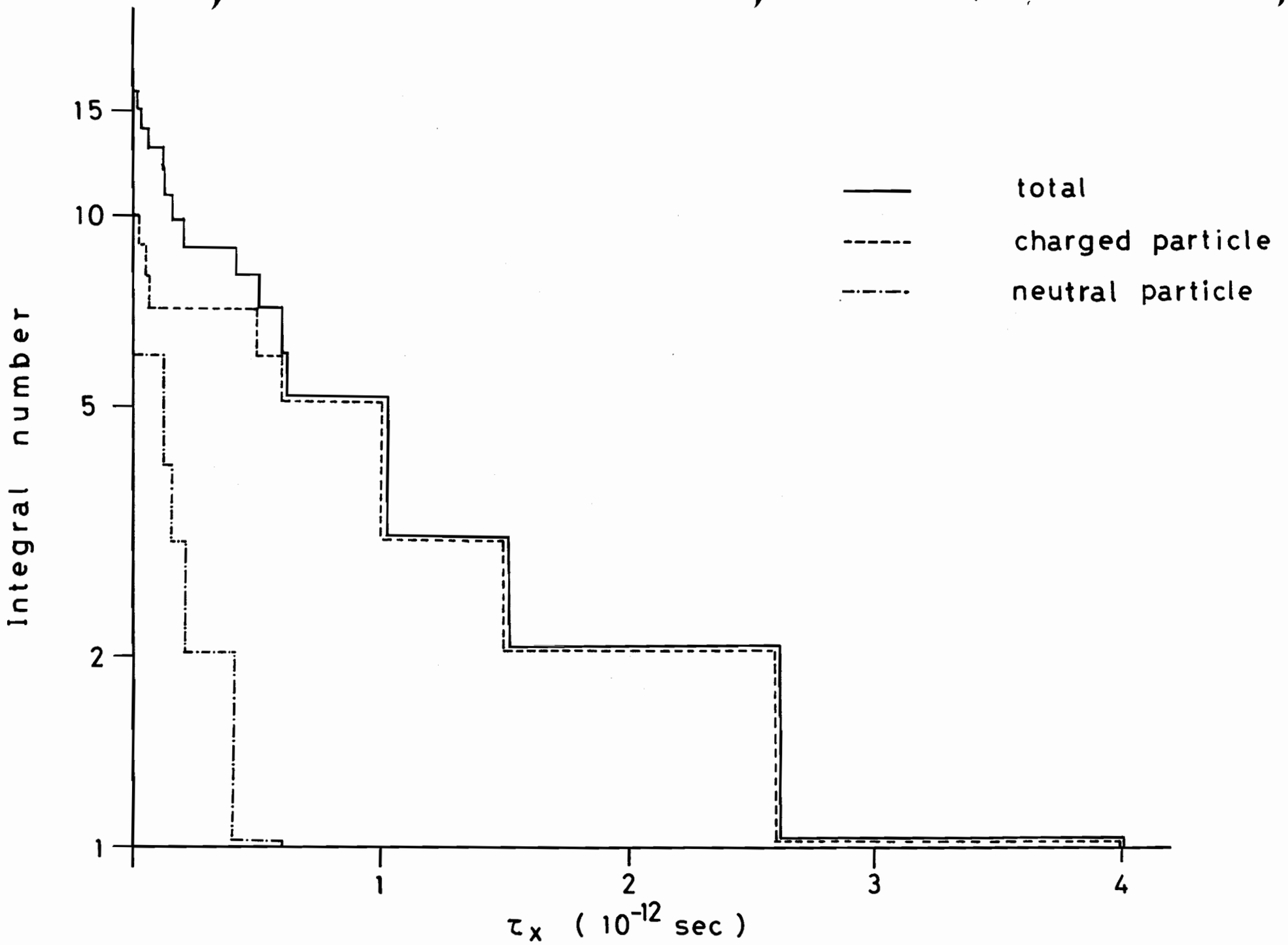
Integral number
15
10
5
2
1
1
2
3
4
τ_x (10^{-12} sec)
total
charged particle
neutral particle

Fig. 4