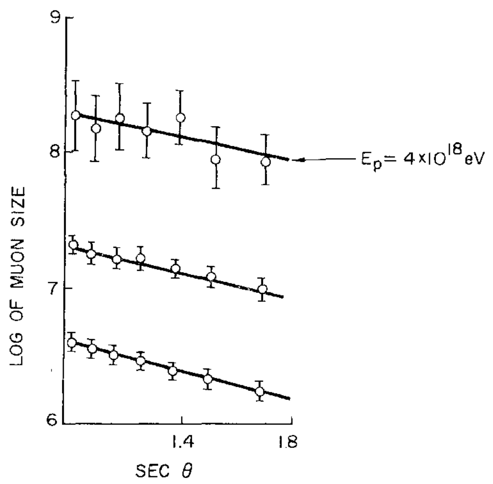
and 'Centauro' events.

§4. Rapid Development of Large Showers

A somewhat different (but possibly connected) phenomenon is the rapid loss of energy of very large cosmic ray air showers [$E_p \geq 10^{17}$ eV]. Figure 3 shows the development curves for showers of three different (muon) sizes as observed by the very large (60 km²) Sydney air shower array. The curves give the change in the number of muons as the shower pass through it atmosphere. θ is the zenith angle of the shower axis. Hence sec $\theta=1$ means a shower at vertical incidence which at sea level was passed through 1010 g/cm² before reaching the detector. One can see that all the showers are declining in size from sec $\theta=1$ (*i.e.*, 1010 g/cm²) to sec $\theta=1.8$ (*i.e.*, 1818 g/cm²), *i.e.*, that even vertical showers are passed their maximum before they reach sea level. Monte Carlo simulations based on "ISR" reaction characteristics predict the opposite. It seems that even at very high energies new phenomena are occurring.



θ IS THE SHOWER ZENITH ANGLE SO SECθ GIVES THE ATMOSPHERE DEPTH.
(FROM 1000 G/CM² TO 1800 G/CM²)

Fig. 3. Development curves for very large air showers. Each curves shows the change in the number of muons in showers of a given primary energy as the shower passes through the atmosphere. Details ref. 3.

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B 10 New Particles in Cosmic Ray Experiments

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Several years in advance the comencement of the 'charmed' age in high energy accelerator physics, a pioneering work on short-lived particle observation had been carried out in the cosmic ray field. In 1971, our group discovered one event[1] showing a pair creation of shortlived particles with life time around 10^{-13} sec and mass around 2 GeV, in the course of investigation of cosmic ray interactions. This particle was named by us as X particle. Es-

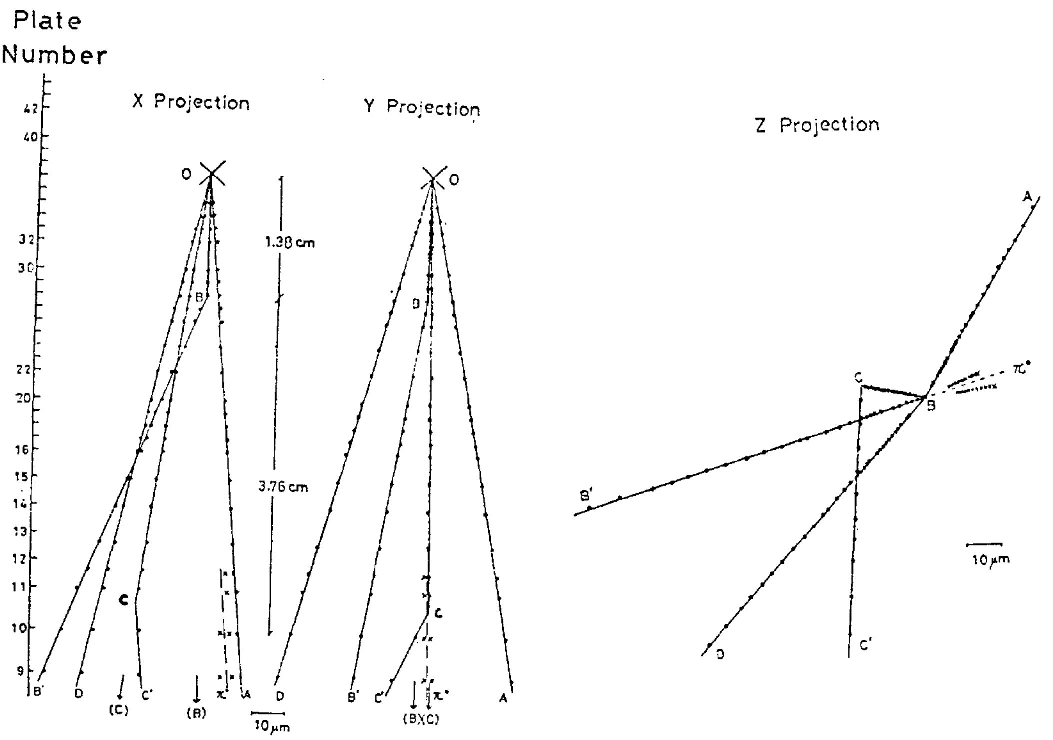

Fig. 1. Most forward part of the Event 6B–23.

	L cm	Dacay mode	M Gev	τ $\times 10^{-13}$ sec
OB	1.28	$\pi^0+K^\pm$	2.15	0.27
		$\pi^0+\Sigma^\pm$	3.5	0.42
OC	4.88	$(\pm)+(0)+$		>15

Table Ia. Event list in which an associated decay of the X particles are observed.

	Charge of primary particle	E_0 (GeV)	n_s	ΣE_γ (TeV)	$E\pi^0$ or γ (TeV)
6B–23[a]	0	10	70	4.5	3.2
T[b]	1	20	36	6	2.4,1.6
ST–2[c]	?	25	51	2.1	1.0
11c–34[d]	0	20	70	8	3.0,1.2,0.6
6a–19L[e]	1	20	18	2.0	
BEC–II[f]	1	10	27	2.7	

[a] K. Niu, *et al.*: Progr. theor. Phys., **46** (1971) 1644,
[b] M. Kaplon, *et al.*: Phys. Rev., **85** (1952) 900.
[c] K. Nishikawa: J. Phys. Soc. Japan **14** (1959) 880.
[d] S. Kuramata, *et al.*: Conf. Papers 13th Int. Cosmic Ray Conf., **3** (1973) 2239.
[e] H. Fuchi, *et al.*: 491, this Conference.
[f] H. Sugimoto, *et al.*: Prog. theor. Phys. **53** (1975) 1541.

Table Ib. Event rate.

Experiment	Number of event	Number of observed jet showers
AEC[a,d]	2	~70
BEC ('56)[c]	1	~20
BEC II[f]	1	~20
Kaplon, *et al.*[b]	1	?
BEC–6[e]	1	27

1 Event/20~40 obs. jet shower

sential points in that event were a pair of kinks in the same event and the coplanarity relation satisfied by a charged tertiary and a neutral pion, as is shown in Fig. 1.

Utilised detector was a so called emulsion chamber which consists of many layers of nuclear emulsion plates and thin lead plates forming a target part and an analysing part. In the target part, cross-sectional view of the secondary tracks of detected interaction is inspected each 1 mm along the shower axis to find any kink or vee. Minimum detectable angle is less than 10^{-4} radian. In the analysing part, we can cleary identify high energy electrons and γ rays by cascade showers they initiate, and also can make analysis of their energy. Momentum of charged particle is also analysed in this part applying multiple scattering method with MDM of TeV/c region.

After the discovery, hunting of the X particles has been continued exposing emulsion chambers at aeroplane and balloon altitudes

Table II. Summary of the X particles.

	L (cm)	θ'/θ		M (GeV)	τ ($\times 10^{-13}$ sec)	
6B–23	1.38	8.92	$\pi^0+K^\pm$	2.15	0.27	
		1.63	or $\pi^0+\Sigma^\pm$	3.5	0.42	pair
	4.88	10.3	$x^\pm+x^0$		~ 15	
T	7.3		$\pi^0+?$		$0.1\sim 1$	pair
	2.5		$\pi^0+?$		$0.2\sim 3$	
ST–2	7.63	21.0	$\eta^0+X^\pm+x^0$	$2\sim 3$	~ 20—	
		9.2			cascade	
		19.6				multi
	1.0	0.21	$\rightarrow x^\pm+x^0$		$<56\leftarrow$	
	8.9	1.3	$x^\pm+x^0$		~ 7	
	8.4		π^0+x^0		6	
11c–34	1.1	3.36	$X^\pm+x^0$		0.4— cascade	
	0.063	0.94	$\rightarrow x^\pm+x^0$	>2	$0.05\leftarrow$	
	1.1		π^0+x^0		~ 1.2	
	6.14		π^0+x^0		~ 1.4	multi
	1.18		$\gamma+x^\pm+x^0$		~ 5	
	1.6		$x^\pm+x^0$		~ 10	
	1.6		$x^\pm+x^0$		~ 10	
6a–19L	0.79	4.76	$x^\pm+x^\pm+x^\mp+x^0$	>1.5	~ 4	
		4.37				
		8.73				pair
	6.1		int		<18	
	0.27	1.07	$\rightarrow x^\pm+x^0$		~ 1	
BEC–II	3.04	2.08	$\eta^0+K^\pm$	1.66	5.1	
		2.46	or $\eta^0+\Sigma^\pm$	2.23		
	6.34	3.49	$\pi^0+K^\pm$	1.74	34	pair
		3.12				
			or $\pi^0+\Sigma^\pm$	2.36		

Table III. Decay type of the X particles.

	$X^\pm$			X^0		
	I 2 body	II ?	III many body	IV 2 body	V ?	VI many body
6B–23	π^0+x					
		$x^0+x^\pm$				
T					$\pi^0+?$	
					$\pi^0+?$	
ST–2			$\eta^0+x^0+X^\pm$—			
		$\rightarrow x^0+x^\pm$				
					π^0+x^0	
		$x^0+x^\pm$				
11c–34		$x^0+X^\pm$—				
		$\rightarrow x^0+x^\pm$				
					π^0+x^0	
					π^0+x^0	
			$\gamma+x^0+x^\pm$			
		$x^0+x^\pm$				
		$x^0+x^\pm$				
6a–19L			$x^\pm+x^\pm+x^\mp+x^0$			
		$x^0+x^\pm$				
BEC–II	$\eta^0+x^\pm$					
	$\pi^0+x^\pm$					
	3	8	3	0	5	0
		14			5	

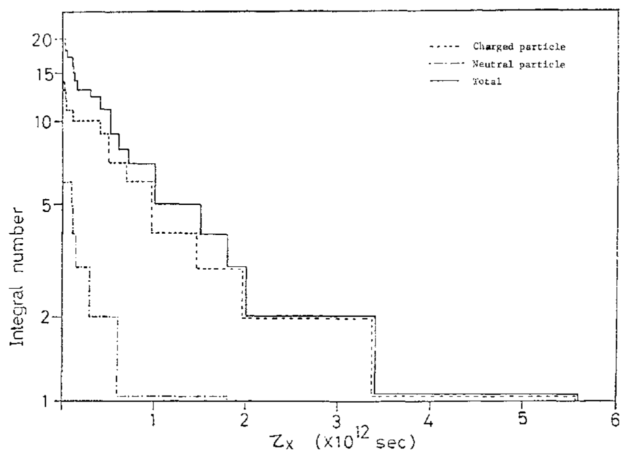

Fig. 2. Life time distribution.

and also making reanalysis of older cosmic ray events ever observed. Table Ia is the event list in which an associated decay of the X particles are observed. In those cases, the background level simulating the true decay of short-lived particles is guaranteed to be of order of 10^{-4} as analysed by Gaisser *et al.*[2] Table II shows the sammary of the X particles with flight path length, ratio of deflection to emission angle, estimated mass and life time. In Table III, they are classified according to the decay type. In two of them, possible new kind of cascade decays and multiple production of the X particles were suggested. Clear case of two body decay is only 3 in 19, and this indicates the dominance of multibody decay of the X particles. Raw charge neutral ratio of observed X particles is 14: 5 including detection bias.

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

Figure 2 shows a distribution of life time of the X particles estimated assuming mass value as 2 GeV. Statistics being not enough, it seems unlikely to fit it with a single exponent. Roughly saying, the mean life time may be of order of $7 \sim 8 \times 10^{-13}$ sec, but two kind of life times, $4 \sim 5 \times 10^{-13}$ sec and $1 \sim 2 \times 10^{-12}$ sec, are also considerable.

For about the production rate of the X particles in the cosmic ray region, it is difficult to estimate it accurately, because of the detection biases. The rate of one event per $20 \sim 40$ observed jet showers of 10 TeV region is a roughly estimated value as is shown in Table Ib.

As mentioned just before, possible new type of cascade decays of shortlived particles are observed rather frequently in the super high energy cosmic ray region. Possible sources of those cascade decays are,

1) Successive decay of a charmed baryon with higher charm, Ξ_c or Ω_c.

2) Decay of new heavy hadron with bottom quark to a charmed hadron followed by a decay of the latter.[3] Though a definite explanation is still difficult at present, those observations seem to suggest an opening of new channels at super high energy region.

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