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Scientific Spokesman:
J. J. Lord
Department of Physics
University of Washington
Seattle, Washington 98105

FTS/Off-Net: 206 - 583-0111
543-2777

PROPOSED EMULSION EXPERIMENT
SEARCH FOR SHORT LIVED PARTICLES AT HIGH ENERGIES

Peter Kotzer
J. J. Lord

University of Washington

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Department of Physics
University of Washington
Seattle, Wa. 98105

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To: Dr. Donald Getz, Secretary
Program Advisory Committee
National Accelerator Laboratory
Batavia, Illinois 60510

From: Peter Kotzer and J. J. Lord
Department of Physics
University of Washington
Seattle, Wa. 98105

April 19, 1972

Scientific Spokesman: J. J. Lord, Prof. of Physics
Telephone: 206 543-2777
or 543-2770

Peter Kotzer

Peter Kotzer, Lecturer

J. J. Lord

J. J. Lord, Prof. of Physics

ABSTRACT

It is proposed to conduct an experiment at the National Accelerator Laboratory concerned with the search for new particles having lifetimes between 10^{-17} and 10^{-12} second. The experiment will be conducted with an emulsion chamber arrangement and will explore for particles with lifetimes too short to be observed directly with other instruments. Two sidelines of the experiment will be concerned with an improved measurement of the lifetime of the neutral pion and the search for gamma ray bundles arising from higher mass resonances which cannot decay by pion emission.

INTRODUCTION

The present-day knowledge of particle production in hadronic collisions is in a somewhat embryonic stage. At least several hundred boson and baryon resonances are considered by theoreticians making calculations with thermodynamic models for particle production. While the properties of resonances are most important, there is reason to feel that current observational techniques and analysis have not yielded significant results commensurate with the effort during the past year or two. Often experiments are found to be in rough agreement with semi-empirical theoretical models, leaving one with the impression that little of fundamental importance has been learned.

While it is important to introduce techniques which go beyond those in use at the present time, it is perhaps more easily said than done. However, it may be in this way that it

is possible to find some special features of particle properties or production which will disclose something of the fundamental nature of the dynamics of particle physics.

The present proposal is concerned with an effort to search for new particles produced by 200-500 Gev protons at the National Accelerator Laboratory, Batavia. The search will be concerned with particles produced in collisions in the nuclear emulsion and having lifetimes in the range of 10^{-17} - 10^{-12} second. The nuclear emulsion is the only instrument which allows direct measurements to be made in this range of lifetimes.

It is presumptuous, of course, to assume that the present proposed experiment will yield information of a fundamental nature. None-the-less, the experiment is of a modest nature and, in the light of recent cosmic ray observations, it could yield new information of a basic nature.

PROPOSED EXPERIMENT

A possible unusual particle was reported by Niu, Mikumo, and Maeda in the Proceedings of the 12th International Conference on Cosmic Rays (Vol. 3 page 1262, Aug. 16-25, 1971). The event was produced in emulsion by a cosmic ray interaction of energy near 10,000 Gev. One emitted particle (described in the paper included in Appendix I of this proposal) traveled a distance of 1.38 cm and then appeared to decay into a charged particle and a π^0 meson. The gamma ray energies from the π^0 were determined and the unknown particle found to have a lifetime of about 10^{-14} sec. and a mass of about 2 Gev/c^2. Since the particle had an energy of several Tev, the lifetime and mass values are not too strongly dependent upon the assumed

mode of decay as shown in Appendix I. In the same event another particle traveled 4.88 cm before decay but its mass and lifetime couldn't be determined.

While one observation doesn't yield a meanlife, Niu's particle seems to have a lifetime quite different from that for known particles. If, on the other hand, the two unstable particles come from the decay of another very short lived particle, its mass would be about 5-10 Gev as estimated from the angles given in Fig. 6C of Niu's paper.

At first glance it looks as if Niu's particle (or particles) should have been observed in experiments at CERN, Brookhaven, or Serpukhov. Since there is a good deal of uncertainty in the particle mass estimates, it could be below the threshhold for production at all accelerators except the ISR at CERN. In the ISR its lifetime may make its detection rather difficult. Another question which may be raised is why it hasn't been observed before in cosmic ray experiments. Niu's use of a plastic-emulsion sandwich stack rather than one of pure emulsion produced a very much slower build-up of electromagnetic cascades. This enabled him to follow tracks out to distances of at least 10 cm before they were obscured by the tracks due to cascades.

Niu's experiment is included as an illustration of the importance of conducting a search for new particles in the lifetime range from 10^{-17} - 10^{-12} second. Basically however, the justification for such a search must be that it is highly important, at the beginning stages of an accelerator, to carry out a few exploratory experiments of a general nature. Hence, it is presently proposed to carry out an experiment similar to that of

Niu's and search for new particles arising from nuclear interactions produced by 200-500 Gev particles.

Another experiment which would be a sideline of this proposal would be concerned with the lifetime of the neutral pion. Direct measurements of the π^0 lifetime have been made many years ago by observing the decay distance of the particle through the decay mode $\pi^0 \rightarrow e^+ + e^- + \gamma$. The observations were made in emulsion and the distance measured from the production point of the π^0 to the origin of the decay electron-positron pair. The average distances were about 0.3 microns compared with the emulsion grain size of about 0.9 microns (after processing). Emulsion measurements gave a mean life of about $1.4 \pm 0.4 \times 10^{-16}$ second while counter experiments through the Primakoff effect gave about $0.7 \pm 0.06 \times 10^{-16}$ second. There is need for a better value of the mean life of the neutral pion.

Neutral pions produced by particles at the NAL energies will have time dilatations about a factor of 10 greater than in the previous experiments. The consequent decay distance in the emulsion would be about 10 times larger which would allow the lifetime to be determined to a precision of about 8% rather than the 30% as given above. The scanning methods used in the experiment to search for new particles would automatically locate the above described neutral pion decay vertices. There would be little additional effort required to make the measurement of the decay distance and to estimate the energy of the pair.

EXPERIMENTAL ARRANGEMENT

Several different types of detectors will be used in the search for new particles produced by the high energy hadronic

interactions at NAL. The main features of the design will be to have a detector which is capable of allowing observations to be made on the decay of short lived particles.

In collisions at 200-500 Gev, speculation can only be made regarding the mode of production and energies of new particles. From particle spectra at Serpukov and the scaling ideas of Bali, Brown, Peccei, and Pignotti, it can be assumed that there will be a good deal of secondary particles emitted at energies of 15 to 20 Gev. Without speculation on the masses or modes of production, assume a time dilation of $\gamma = 10$ for the new particles. In this case lifetimes of 10^{-17} to 10^{-12} second will lead to decay paths from 3×10^{-5} mm to 3 mm. While the best resolution of the emulsion is about 3×10^{-4} mm, the lower lifetime limit would still allow the detection of lighter particles. For example, the neutral pion having a time dilation value of $\gamma = 500$ would have a decay distance of 15×10^{-3} mm, about 50 times greater than the resolution of the emulsion.

Unstable particles such as those found by Niu et al would have a mean decay length of the order of 0.1 to 0.5 mm at NAL energies. This is based on extrapolations from the cosmic ray experiments wherein the time dilation factor would be reduced by a factor of about 100. In addition, for decay distances greater than about 1 mm, observations could be made much more effectively with bubble chambers.

Niu et al found their events out of a sample of about a dozen interactions which had undergone careful examination. At NAL energies we plan to examine about 5000 interactions for evidence of decays or pair production within 1 mm of the point

of interaction. Although one emulsion plate would provide sufficient statistics for the experiment, a large stack will be needed to study the nature of the tracks after a decay. As shown in Fig. 1, a stack 7 cm x 15 cm x 3 cm will provide the main detector for the experiment. There would be 50 pellicles in the stack each 600 microns in thickness and made of Ilford G-5 emulsion.

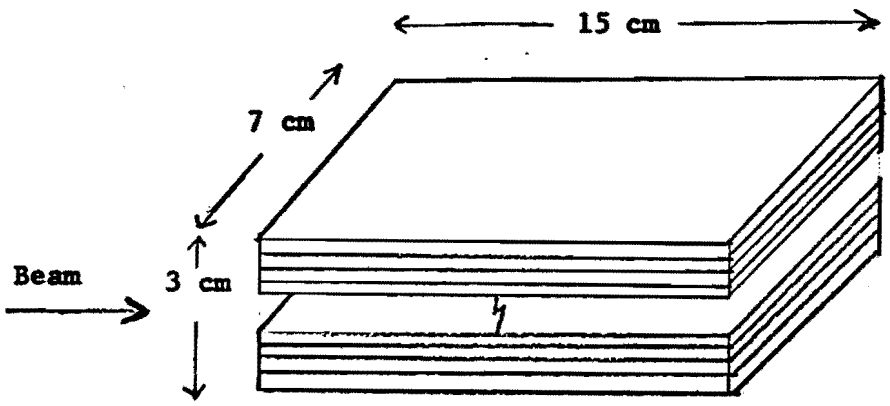

FIG. 1

50 Ilford G-5 pellicles, 600 microns thick

It is proposed to expose the stack to 90,000 particles / cm^2 of the highest energy available at NAL. This intensity is about the maximum that will allow individual tracks to be followed with sufficient precision to locate evidence for a decay. Naturally, many test exposures would be made to be sure of the proper flux.

Several smaller stacks will be made up to study the high energy events with a view of detecting gamma rays. The arrangement, shown in Fig. 2, is made up of a sandwich of emulsions and lead plates. It is held together in a frame made of two brass pins which allow alignment of the plates with a precision of about 5 microns. A larger precision sandwich stack of this type has been described by Gibbs and Lord (Acta Physica Academiae 29 Suppl. 3, 113, 1970). The proposed arrangement shown in

Fig. 2 will be employed to search for gamma rays from the high energy nuclear interactions or the decay products of unstable particles.

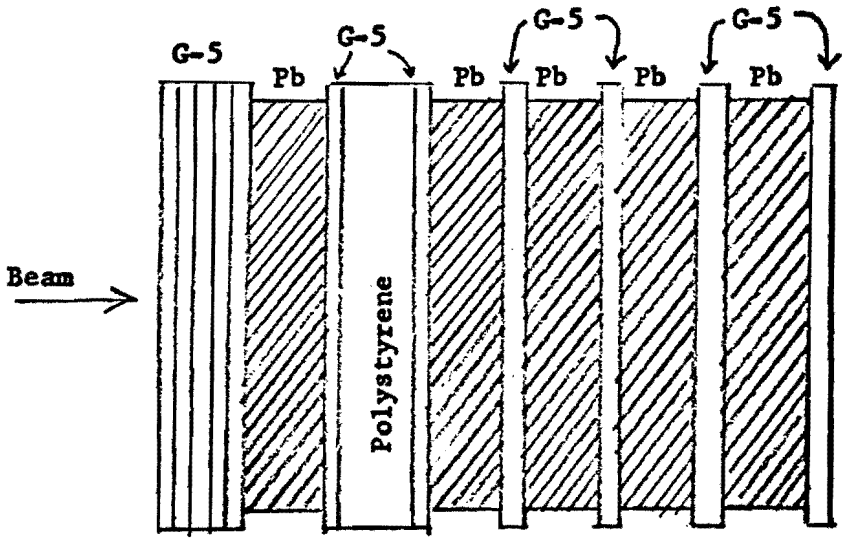

FIG. 2

All emulsions are Ilford G-5

As shown in Fig. 2 there will be a small producing region consisting of 5 pellicles, 600 microns in thickness, located on the beam side of the detector. After that there will be a 1 mm thick Pb plate (1/5 radiation length in thickness) followed by an 800 micron thick polystyrene plate with 300 microns of emulsion on either side. The latter double coated emulsion allows accurate angle measurements to be made for single tracks and electron pairs. An additional sandwich of 4 Pb plates and emulsions provides about 1 radiation length of material between the high energy event and the detector plate. This arrangement is similar to the gamma ray detection system employed by Niu et al. It will allow the detection of gamma rays originating from the decay of the unstable particles being sought in this experiment. Naturally, in this case, the gamma rays will be of very much lower energy than found in the cosmic ray experiment. However, the alignment arrangement of the stack will allow accurate

angular measurements of individual electron-positron pairs for correlation with decay events.

The producing layer as shown in Fig. 2 is quite thin and a flux of 10,000 particles per cm^2 through the five pellicles will give about one interaction per mm^2 of the cross sectional area. This density of events is sufficient to allow good correlation of the gamma rays with events.

While many experiments with counters and bubble chambers will search for new particles at the National Accelerator Laboratory, they will be restricted to those having lifetimes larger than 10^{-12} sec. or the very short lifetimes of the resonances. The present experiment is designed to search in a region not accessible to counter or bubble chambers, ie. $\tau = 10^{-17}$-10^{-12} second. It is also a search wherein there is cosmic ray evidence for a particle of lifetime 10^{-14} second and having a mass less than perhaps 3 Gev.

The proposed experiment is simple and can be carried out with only one or two pulses of particles from the accelerator.

A second sideline experiment which is possible with the arrangement of Fig. 2 will be the search for gamma ray bundles arising from the decay of higher mass resonances which cannot decay by pion emission. The regge trajectories for meson and baryon families have at most only three or four members. The meson trajectories vary linearly with the square of the rest mass while the baryon trajectories are linear with respect to the mass. At higher J values (5 or 6) the difference in mass

may be less than the rest mass of the pion. In this case the only decay mode might be through the emission of a gamma ray with $\Delta J = 1$. If the J is quite large the meson might decay stepwise into four or five gamma rays. At the NAL energies a small bundle of gamma rays would be emitted.

In the proposed experiment the emulsion sandwich detector will have 1 mm lead plates for the purpose of detecting gamma rays. This feature of the detector would give a finite chance to locate and estimate the energy of a gamma ray bundle. While gamma ray bundles will be looked for in the scanning, the emulsion sandwich detector is not too satisfactory an instrument in the search for low energy gamma rays. The main effort in the proposed experiment will remain, as noted before, the search for new particles as described above.

ACCELERATOR ARRANGEMENTS REQUIRED

While only two emulsion stacks are needed for this experiment, it would be well to prepare a few additional ones in order to obtain the optimum exposures. A summary of the proposed exposures follows:

Stack	Approx. size	Type of particle and energy	Total exposure
# 1	2"x3"x6"	protons 200-500 Gev	50,000 per cm^2
# 2	2"x3"x6"	protons 200-500 Gev	90,000 per cm^2
# 3	2"x3"x6"	protons 200-500 Gev	120,000 per cm^2
# 4	5"x5"x4"	protons 200-500 Gev	10,000 per cm^2
# 5	5"x5"x4"	protons 200-500 Gev	30,000 per cm^2
# 6	2"x3"x6"	neutrons 200-500 Gev	500,000 per cm^2
# 7	2"x3"x6"	neutrons 200-500 Gev	800,000 per cm^2

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Appendix I

(from: Proceedings of 12 th Int. Conf. on Cosmic Rays, Vol. 3, page 1262, Aug. 1971)

Observation of High Energy Interactions at Aeroplane Altitute

K. Niu and E. Mikumo

Institute for Nuclear Study, University of Tokyo

Y. Maeda

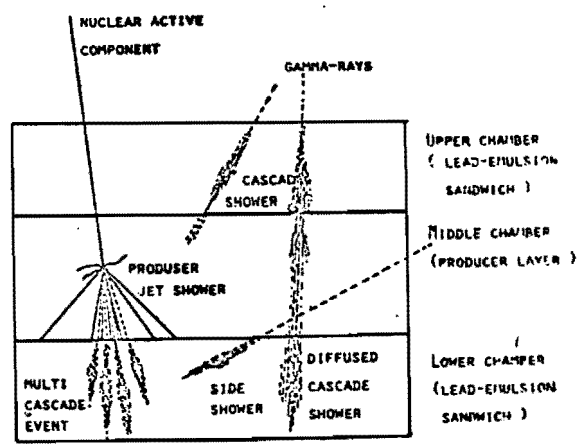
Yokohama National University

An analysis is presented on a nuclear interaction observed by emulsion chambers with producing layers exposed at an aeroplane altitude. Among secondary particles produced in a high energy jet shower, a possible decay in flight of a particle of unknown type was found.

1. Introduction. In order to investigate super high energy jet showers in full detail combining the informations about secondary charged particles at or near an origin of jet shower as well as γ ray component, a new type of emulsion chamber with producing layer was developped, and exposed to cosmic rays. The measurement and analysis on jet showers observed are now going on, and here the report is limited only about an event already analysed.

2. Design of the chamber. The emulsion chambers for this experiment consisted of three parts as shown in Fig. 1. These are: upper chamber as a detector of γ rays coming from the upper atmosphere; middle chamber with material producing jet shower, which is also used as an analyser of charged component from jet shower; and lower chamber as an analyser, as well as a detector of γ rays produced by the jet shower in the middle chamber.

Fig. 1. Schematical illustration of the emulsion chamber with producing layers.



To minimize the development of cascade showers and occurrence of secondary jet showers initiated by secondary particles in the producer layer, and to observe a crossectional view of jet showers each 1 mm along the shower axis, we adopted, as a producer, a pile of nuclear emulsion plates with a 50 μm coating on both sides of meta-acryl base with a thickness of 800 μm.

A typical design of the chamber is shown in Fig. 2. The middle chamber is a pile of 49 layers of nuclear emulsion plates with X-ray films and 5 lead plates with thickness of 1 mm. The thickness of this pile is 7.3 cm and this corresponds to 0.1 nuclear interaction mean free path and 0.3 (Emulsion plates) + 1.0 (Lead plates) cascade unit. The total size of this chamber is 20 cm × 25 cm × 19 cm, and the weight is about 50 kg including the packing case.

3. Exposure and scanning. Exposure of this type of emulsion chamber in the upper atmosphere, about 260 gr/cm², was performed using a Jet Cargo Aeroplane of Japan Air Lines from August to December 1969. In total, 12 chambers were exposed with an effective exposure of 400 ∿ 600 hours.

The scanning for jet showers was made through the following scanning program. At first, there is selection of those multi γ rays events in the lower chamber whose primary particle come through upper chamber leaving no ~~sign~~ shower there, and next following back shower tracks up into the producing layers and detection of the origin of jet shower.

4. Event "6B-23"

a) General description of the event. One of jet shower observed in these chamber, Event "6B-23", was fortunately produced in the emulsion of lower surfase of plate No.38 in the middle of the producer layer. Therefore, type of this jet shower was observed as (19+70)n. Schematical view of this jet shower is shown in Fig. 3.

Analysing on cascade showers of this event in the lower chamber we get 23 cascade cores. Emission angles of charged particles, were estimated using target diagramms on each emulsion surface in the producer layer. Following down these particles into the lower chamber, we found that 4 of the 23 cascade showers belong to secondary interactions induced by charged secondary particles.

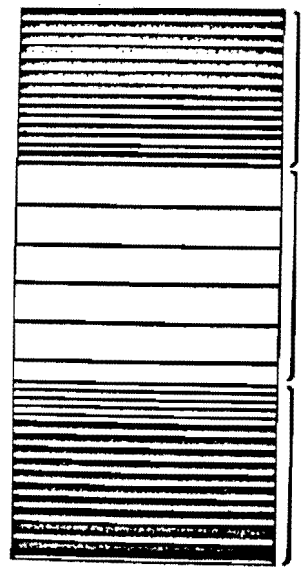
Target diagramm of cascade cores at plate No.7, 6.63 cm from the origin of jet shower is shown in Fig. 4, with estimated energy of each cascade shower. Pairs of γ rays coupled with line in this figure are posible π^0 mesons whose production hights are coincide with the origin of the jet shower within the error of 10 %. From this analysis our method of energy determination of γ rays was confirmed.

Fig. 2. Design of Emulsion Chamber with Producer Layer

SIZE: 20cm x 25cm x 19cm

: LEAD PLATE

: SENSITIVE LAYER



Upper Chamber

LEAD PLATE (2.5mm)	7
LEAD PLATE (1.5mm)	8
NUCLEAR EMULSION AND X-RAY FILMS	15

Middle Chamber(producing layer)

NUCLEAR EMULSION AND X-RAY FILMS	49
LEAD PLATE (1mm)	5

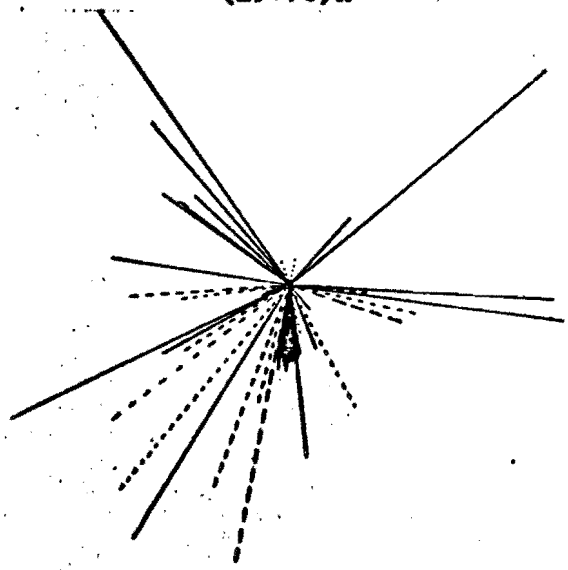
Lower Chamber

LEAD PLATE (1mm)	5
LEAD PLATE (2.5mm)	8
LEAD PLATE (5mm)	2
NUCLEAR EMULSION AND X-RAY FILMS	15

Fig. 3

EVENT 6B-23

(19+70)n



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In Fig. 5 is shown the relation of energy to lg.tg θ for γ rays with lg·tgθ distribution of charged secondary particles. Though the jet shower "6B-23" is produced by a complicated collision of neutral primary particle with Ag or Br nuclei in the emulsion, the angular distribution of charged particles shows two fire ball like structure. Comparing anguler distribution of γ rays with that of charged particles, it is seen that we observed neary 2/3 of γ rays of forward fire ball. From this, threshold energy to detect γ rays in this case turns out to be about 40 Gev.

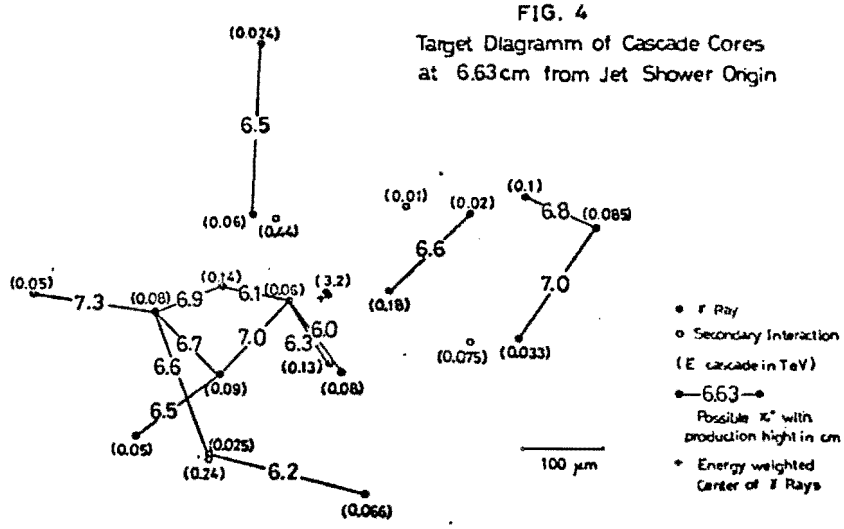


FIG. 4
Target Diagramm of Cascade Cores at 6.63 cm from Jet Shower Origin

b) Central part of the event. The most impressive feature of this jet shower is that 2 γ rays whose energy are nearly one order higher than others are emitted very closely in the center region of shower. Relative distance between those γ rays is 3.4 μm at the plate No. 10. Because of a very small distance between them, independent energy determination for each γ ray could not be possible. We estimated total energy of these γ rays as 3.2 ± 0.4 Tev. Compareing size of both cores, energy ratio of these two γ rays is estimated as ∿ 2:1. Coupling these two γ rays into a π^0 meson, the estimated production hight is 3.8 ± 0.5 cm above the plate No. 10, and it is smaller than the hight of origin of primary jet shower, 5.14 cm.

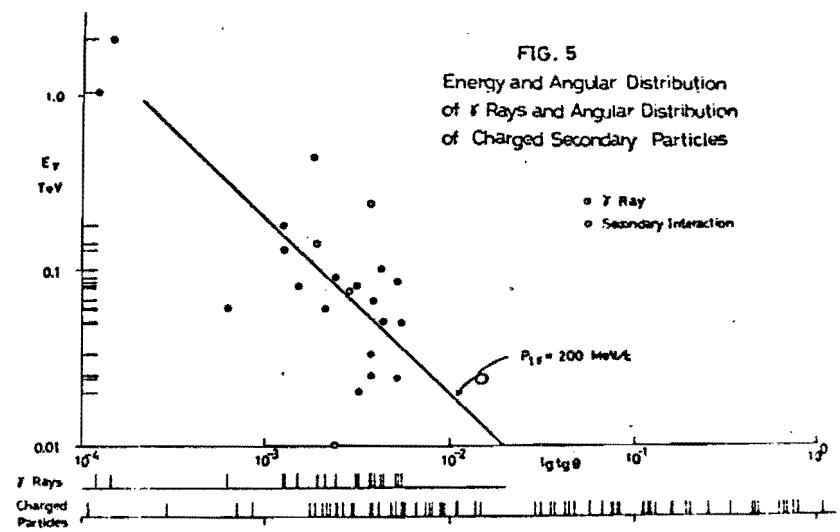


FIG. 5
Energy and Angular Distribution of γ Rays and Angular Distribution of Charged Secondary Particles

There emitted 4 charged particles very near to these γ rays. We drew presise target diagramm of tracks of these 4 particles A, B, C, and D at each emulsion surface in the producer layer, and then reconstructed three dimensional view of tracks of these particles and π^0 meson. X, Y, and Z projection of these tracks are shown in Fig. 6 a, b and c. We adopted Z axis parallel to the emitted direction of track B.

As you can see from X and Y projections, track B and C have knees at 1.38 cm

cm and 4.88 cm respectively from the origin of jet shower and the angle of direction change of tracks are 1.07×10^{-3} radian, and 1.50×10^{-3} radian respectively.

Looking at the Z projection, you can easily recognize that the two cascade cores from π^0 meson appear in just the opposite direction of Z projection of track B', and particles B, B' and π^0 meson satisfy the coplanarity condition. The emission angle of π^0 meson from the point of direction change of track B is 1.96×10^{-4} radian.

We followed down the track B' and C' to the bottom of lower chamber the thickness of which is 7 cascade unit, and found nothing assosiated with tracks B' and C' before their leaving the chamber. Therefore, the track B' and C' might be produced by hadronic particles. Inspecting near arround the point of direction change of track B and C, no track assosiated with these points was found.

c) A possible two body decay of X particle. Basing on the features mentioned above, it is possible to attribute the phenomenon including track B, B' and π^0 meson to a two body decay of X particle into a π^0 meson and a charged hadron.

Transverse momentum of π^0 meson to the initial direction of track B is estimated as 627 Mev/c from its emission angle and observed energy. This value is also applied for that of particle B' in the case of two body decay. From this we get the momentum of particle B' as 0.59 Tev/c.

Assuming $\pi^{\pm}$ meson or proton as a partner of π^0 meson, mass and life time of X particle are got as shown in Table 1.

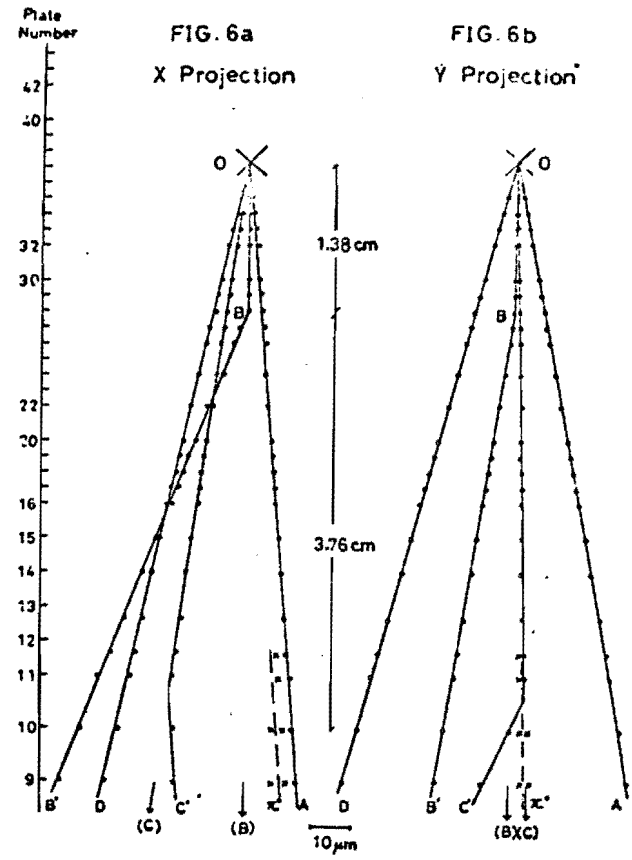
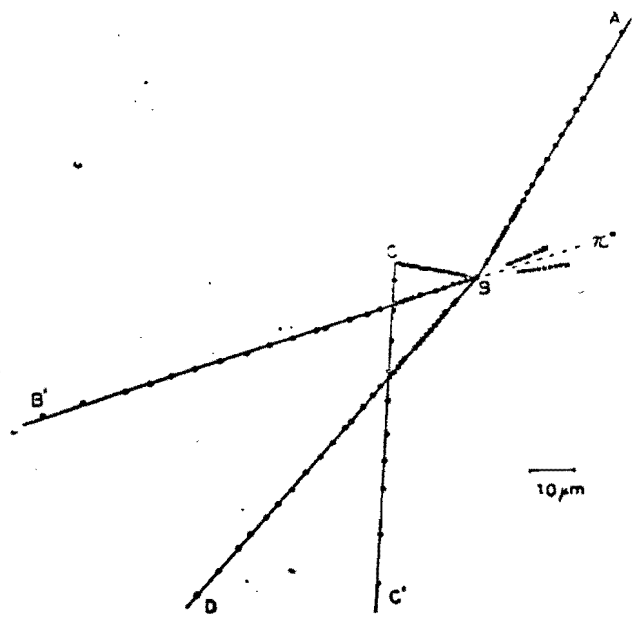


FIG. 6c
Z Projection



5. Discussions. As far as γ rays concerned, there observed sometimes "6B-23" like events in Emulsion Chamber Experiment on Mts. Norikura and Chacaltaya.[1] In Bristol Bombay Experiment[2] with a balloon exposed emulsion chamber, there observed several such events amoung 44 jet showers with $\Sigma E\gamma > 1.3$ Tev. Babayan et al[3] also reported the existence of high energy events in which appreciable fraction of primary energy is transferred to a single π^0 meson. Some of these events might have the same characteristics as our event "6B-23". Japan Brasil collaboration group of emulsion chamber called this type of events as "Torpedo", and they attributed this to a new state of matter with anisotropy. Combining the information about charged secondary particles as well as the γ ray component of jet shower, we were able to analyse this type of event more presisely and got above results.

Table 1

Assumed decay mode	M_X Gev	T_X sec.
$X \rightarrow \pi^0 \pi^{\pm}$	1.78	2.2×10^{-14}
$X \rightarrow \pi^0 N$	2.95	3.6×10^{-14}

The possibility of this type of event produced by secondary interaction or chance coincidence of elastic scattering of one of charged secondary particle and original π^0 meson so emitted as to satisfy coplanarity condition is very small as is shown in Table 2.

Table 2

Process	Path length from jet shower origin to upper surface of lower chamber x/λ int	Ratio of crossection of the process to total crossection. σ/σ tot	Probability of $E_{\pi^0} > \frac{3}{4}E_0$ or $E_{\pi^0} > \frac{3}{4}\Sigma E\gamma$.	Probability to satisfy coplanarity condition within 1°.	Total probability
One π^0 meson production in secondary interaction.	0.055	0.026	< 0.1	0.067	$< 0.96 \times 10^{-5}$
Elastic scattering of secondary particle and π^0 meson produced in primary jet shower.	0.055	0.156	< 0.1	0.0028	$< 2.4 \times 10^{-6}$

As for the charactoristics of X particle the transverse momentum of π^0 meson, 627±90 Mev/c, is much higher than maximum momentum of decay products of existing strange particles. The life time of assumed X particle is several times 10^{-14} seconds and this is extremely longer than those of resonance particles. Therefore, our X particle could not be included neither in strange particle nor resonance particle.

If the direction change of track C at 4.88 cm from jet shower origin is attributed to a decay of particle C into a hadronic particle C' and a neutral hadronic particle, maybe we are observing a pair production of new type of particles.

Being informed about this event, S. Ogawa et al[4] reached a conclusion that

our X particle must be such a particle which has a new quantum number and is produced in pair in super high energy strong interactions. Attributing this to p' particle which is the fourth type of fundamental baryon corresponding to 4 leptons, and assuming hyperon like 2 body decay bia weak interaction of this new particle with mass of 2.95 Gev, they estimated mean life time of this channel to be 3.2×10^{-13} sec.

Of course, it is also possible to attribute one of the decay products of the X particle which produced track B' or track C' to a μ meson. Then, there might be other possibilities to interprete this type of event.

We are now continuing to search for new type of particles, and we have another possible example of pair production of X particles produced in supar high energy interaction.
One of charged secondary particle suffered direction change after about 1 cm flight, and another possibly decayed into three charged hadronic particles after about 2 cm flight. Full detail of this and other events will be published elsewhere.

Finally Table 3 is a short summary of reasons why this type of particle cannot be identified by other experimental method.

Table 3

Experimental method	The reason why this type of particle cannot be found.
Experiments in high energy accelerator region.	The Lorentz factor and then the flighting path of produced new particle, if it is produced, is too small to idetify. In case of pair production, incident energy is not sufficient because of higher threshold of production.
Emulsion chamber experiment in cosmic ray region.	Observation is limitted mainly in γ rays and information about charged secondary particles at or near the origin of jet shower is omitted.
Emulsion stack experiment in cosmic ray region.	One cascade unit corresponds to 3 cm in emulsion stack and many γ rays initiate cascade showers earier than let them identify this type of particle.
Other track detecter or counter experiments in cosmic ray region.	Observation is limitted mainly in charged secondary particles at more than several cm down from jet shower origin and observation of individual γ ray is hardly possible.

Acknowledgements. The authors would like to express their gratitude to members of Japan Air Lines, especially to Mr. Harada, for making successful exposures at aeroplane altitudes. Thanks are also due to Dr. T. Sueyoshi of Fuji Film Company for making emulsion plates coated on both sides of thin meta-acryl bases.

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