XXV REunião de Trabalho sobre INterações HAdrônicas – RETINHA XXV

UNIVERSIDADE ESTADUAL DE CAMPINAS-UNICAMP

INSTITUTO DE FÍSICA ‘GLEB WATAGHIN’ -IFGW

5-7 de Fevereiro de 2014

High Energy Interactions & Multiple Meson Production

5^{th} School on Cosmic Rays and Astrophysics

UNIVERSIDAD MAYOR DE SAN ANDRÉS-UMSA
FACULTAD DE CIENCIAS PURAS Y NATURALES
INSTITUTO DE INVESTIGACIONES FÍSICAS-IIF
LA PAZ - BOLIVIA
From August 22^{rd} to August 31^{st}, 2012

High Energy Interactions & Multiple Meson Production

First of all I would like to acknowledge the invitation to participate of this school. Also I would like to apologize for my absence due to private circumstances that doesn't allow me to meet worldwide friends.

To be presented by Profs. Oscar Saavedra, Luiz Vitor de Souza Filho, Marcelo A.Leigui de Oliveira

Introduction

- This talk is almost de same as presented at UFABC – Santo André – SP,Brasil, from August 25 to September 04, 2010.

- There and here I am using mainly the following 3 main references:
- a) Y.Fujimoto & S.Hayakawa, Cosmic Rays and High-Energy Physics, Handbuch der Physik vol.XLVI/2-Cosmic Rays II, Springer-Verlag,(1967), 115-180
- b) E.L.Feinberg, Multiple Production of Hadrons at Cosmic Ray Energies (Experimental Results and Theoretical Concepts), Physics Reports (Section C of Physics Letters) 5, no.5,(1972),237-350. An interesting statement of this paper is the pioneering aspect of some theoretical models used by cosmic ray experiments.
- c) Brasil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment, Supplement of the Progress of Theoretical Physics, No.76,(1983),1-39

Introduction

Cosmic Rays and High-Energy Physics.

By

Y. Fujimoto and S. Hayakawa.

With 36 Figures.

I. Discovery of multiple production.

1. Early theoretical attempts. Around 1930 a number of cosmic-ray phenomena were discovered which did not seem to fit within the framework of the existing theory of elementary particles, and were thought by some physicists to indicate the need for a new theory. Among them, the multiple production of secondary particles by a cosmic-ray particle passing through matter was the most typical one; the bursts observed with ionization chambers and the showers observed with counter coincidences and cloud chambers were regarded as evidence for multiple production. At about the same time many other cosmic-ray phenomena were successfully explained by quantum electrodynamics, which predicts the occurrence of a higher order process only with a probability as small as a power of the fine structure constant, $\alpha = 1/137$. It was, therefore, felt that multiple production was a phenomenon contradicting quantum field theory.

This point of view was emphasized by several authors, among them Heisenberg (*1*). He was motivated by his own theory of nuclear forces in which the exchange of a pair of fermions between two nucleons was assumed to be the origin of the force. There he noticed that the coupling constant of this interaction had the dimension of a length, so that at very high energies the interaction energy could become greater than the energy of the free fields. Multiple production was believed to be associated with this particular feature, because the perturbation method which was considered as an inherent part of quantum electrodynamics would no longer be valid in a field theory of this kind. The model adopted by Heisenberg was found to be inadequate after the proposal of Yukawa's meson theory, and furthermore most of those phenomena which had been attributed to multiple production were successfully interpreted as due to the cascade showers and evaporation stars from nuclei. Nevertheless, the perturbation method was considered to be not applicable for the strong interaction of the meson with the nucleon, and the discovery of the penetrating showers offered stronger evidence than before for the existence of the multiple production process. Therefore an essential part of Heisenberg's idea could not be abandoned. On the basis of meson theory Heisenberg (*2*) pointed out that the strong interaction should lead to a large probability for large momentum transfer, for which the existing theory would break down, and a new theory with a universal length should be introduced. Although the original forms of Heisenberg's proposal have now become merely of historical interest, their essential points still remain valid.

The strong interaction will show a characteristic behaviour when the interaction energy becomes greater than the energy of a free meson. The distance within which this situation happens is defined as a characteristic length l, and in the region of dimension smaller than l a conventional quantum mechanical treatment

PHYSICS REPORTS (Section C of Physics Letters) 5, no. 5 (1972) 237–350. NORTH-HOLLAND PUBLISHING COMPANY

MULTIPLE PRODUCTION OF HADRONS AT COSMIC RAY ENERGIES (EXPERIMENTAL RESULTS AND THEORETICAL CONCEPTS)

E.L. FEINBERG

P.N. Lebedev Physical Institute, Academy of Sciences of the USSR, Moscow

Received 10 April 1972

Abstract:

Experimental cosmic ray data on hadron interactions are reviewed (Part I). Specific features of cosmic ray experiments and specific methods used are briefly described. The data which may be considered as definitely established and accepted by all cosmic ray investigators are separated from those results which are not yet proved but, being of utmost importance, deserve serious attention. Besides, some indications of possible new phenomena at laboratory impinging energy $E_L \sim 10^4 - 10^5$ GeV are described. Among the most essential suggestions arisen from cosmic ray studies particularly stressed are: first, the division of produced particles into two groups – pionization (these constitute an overwhelming majority of final particles) and leading ones – with sharply different kinematic properties; second the tendency of multiple production of particles to proceed via formation of clusters, whose properties correspond to those of a statistical system with temperature of the order of the pion mass.

Theoretical ideas, models and theories pertaining to multiple production are reviewed in Part II. It is shown that actually both popular and discarded ones use rather few basic principles. The pionization and interaction of produced particles among themselves are essential for interpretation of experimental data.

The dominating process at very high energy seems to be a peripheral process with statistical subsystems included in a peripheral or multiperipheral scheme.

With the energy range of $E_L \lesssim 10^3$ GeV scaling holds for leading particles and fails to be valid for the pionization ones. The true asymptotics may appear only at higher energy.

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Introduction

Fire-Balls in Pion Multiple Production

——Brasil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment——

Jose A. CHINELLATO, Carola DOBRIGKEIT, J. Bellandi FILHO,
Cesar M. G. LATTES, Marcio J. MENON, Carlos E. NAVIA O.,
Ammiraju PEMMARAJU, Kotaro SAWAYANAGI,
Edison H. SHIBUYA and Armando TURTELLI Jr.

Instituto de Fisica Gleb Wataghin, Universidade Estadual de Campinas Campinas, S. P.

Neuza M. AMATO, Naoyuki ARATA and F. M. Oliveira CASTRO

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, R. J.

Regina H. C. MALDONADO

Instituto de Fisica, Universidade Federal Fluminense, Niteroi, R. J.

Hiroshi AOKI, Yoichi FUJIMOTO, Shunichi HASEGAWA,
Hiroshi SEMBA, Masanobu TAMADA,
Kojiro TANAKA and Seibun YAMASHITA

Science and Engineering Research Laboratory, Waseda University Tokyo 162

Toru SHIBATA and Kei YOKOI

Department of Physics, Aoyama Gakuin University, Tokyo 157

Hiroshi KUMANO, Akinori OHSAWA and Takaaki TABUKI

Institute for Cosmic Ray Research, University of Tokyo Tanashi, Tokyo 188

(Received August 26, 1982; Revised February 14, 1983)

The article describes a study of the multiple pion production through observation of gamma-rays produced by nuclear interactions at the target layer of the emulsion chambers exposed at Chacaltaya, Bolivia, 5200 m above sea level. The analysis was focused on 80 events with $\Sigma E_\gamma > 20$ TeV, well above the detection threshold of the X-ray film spot scanning, ~3 TeV. The distribution of gamma-rays is constructed on their energy, p_t, and emission angle, and the comparison is made with the results from the simulation calculations based on FNAL hydrogen bubble chamber events and ISR minimum bias events. The cosmic-ray results are significantly out of the simple

Introduction

- Since the time of this school
- (September 19-30, 1988), I am
- feeling uncomfortable with the
- title: High Energy Interactions.
- Everybody agrees that this
- concept is relative and we must
- be clear about the range we are
- talking about.

C I F

I Curso Internacional Sobre Rayos Cósmicos

La Paz, Septiembre 19 - 30 de 1.988

El Centro Internacional de Física con el auspicio del International Centre for Theoretical Physics ICTP de Trieste, convoca a los físicos y especialistas en el campo de los Rayos Cósmicos a su primer curso internacional sobre este tema, el cual se realizará en La Paz, Bolivia, del 19 al 30 de Septiembre de 1.988.

Propósitos:

- Presentar un panorama actualizado del estado de la investigación mundial en Rayos Cósmicos.
- Incentivar la conformación de proyectos de investigación en el área en América Latina.

Profesores y Temática:

Directores:
- Nunzio Iucci - Universidad de Roma
- Carlos Aguirre - Junta del Acuerdo de Cartagena - Lima

Profesores:

N. Iucci	- Italia	- Modulación Solar.
C. Aguirre	- Bolivia	- Investigación sobre Rayos Cósmicos en América Latina.
O. Saavedra	- Bolivia	- Neutrinos y Rayos Cósmicos.
E. Shabuya	- Brasil	- Interacciones de Alta Energía.
M. Storinio	- Italia	- Pasado y presente de los Rayos Cósmicos.
K. Suga	- Japón	- Chubascos extensos.
J. Linsley	- E.E.U.U.	- Chubascos extensos.
R. Santónico	- Italia	- Nuevas técnicas para chubascos extensos.
P. Spillantini	- Italia	- Investigación de Rayos Cósmicos con satélites.
V. Pirronello	- Italia	- Interacción de Rayos Cósmicos de Baja Energía con Materia Interestelar.

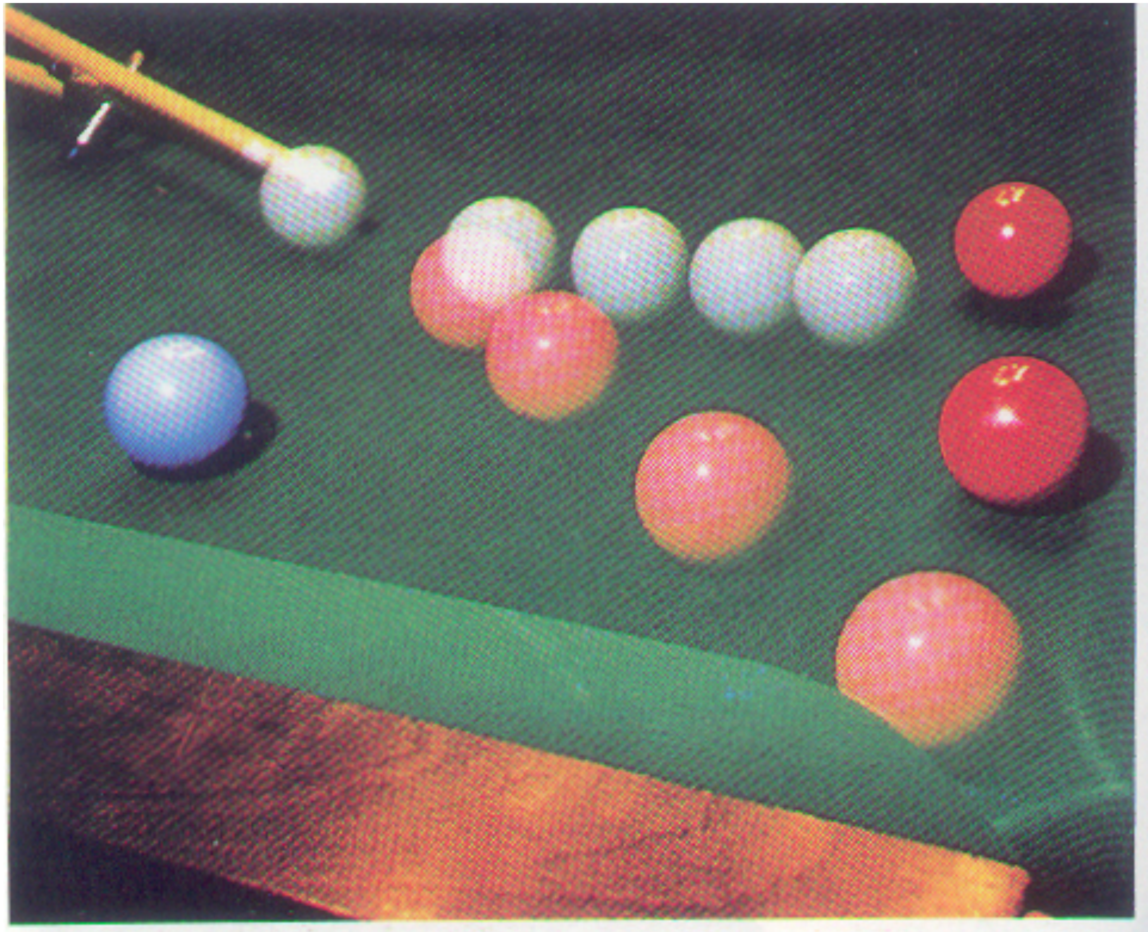
Participación: El curso está abierto a Físicos y especialistas en Rayos Cósmicos de cualquier país. Sin embargo, está especialmente orientado hacia los científicos de América Latina. Los interesados en participar deberán diligenciar el formulario CIF de solicitud de participación anexo al presente boletin o que se puede obtener en los Departamentos de Física de casi todas las Universidades de la región y enviarlo sin usar correo recomendado, o preferiblemente, por Telefax, a:

Introduction

- Concept of high energy
- keV? – domain of Atomic Physics
- MeV? – domain of Nuclear Physics
- GeV? – domain of ‘Fundamental’ Particle Physics
- TeV? – today’s research energy
- PeV? – LHC’s energy = 26 PeV
- EeV? – GZK’s cutoff = 100 EeV
- ZeV? – Planck mass = 1.22×10^7 ZeV/c^2

Introduction

- What's difference between collision of protons, electrons, etc. with collision like this one?



Introduction

- A remarkable observation in the energy range of the order of 100 MeV/c is the $\pi-\mu$ decay both in Cosmic Rays and in Accelerator experiments in 1947 (C.M.G.Lattes, H.Muirhead, G.P.S. Occhialini and C.F.Powel) and in 1948 (E.Gardner and C.M.G.Lattes) & (J.Burfening, E.Gardner and C.M.G.Lattes), respectively.

Introduction

- Incomplete $\pi-\mu$ decay at Pyrénées

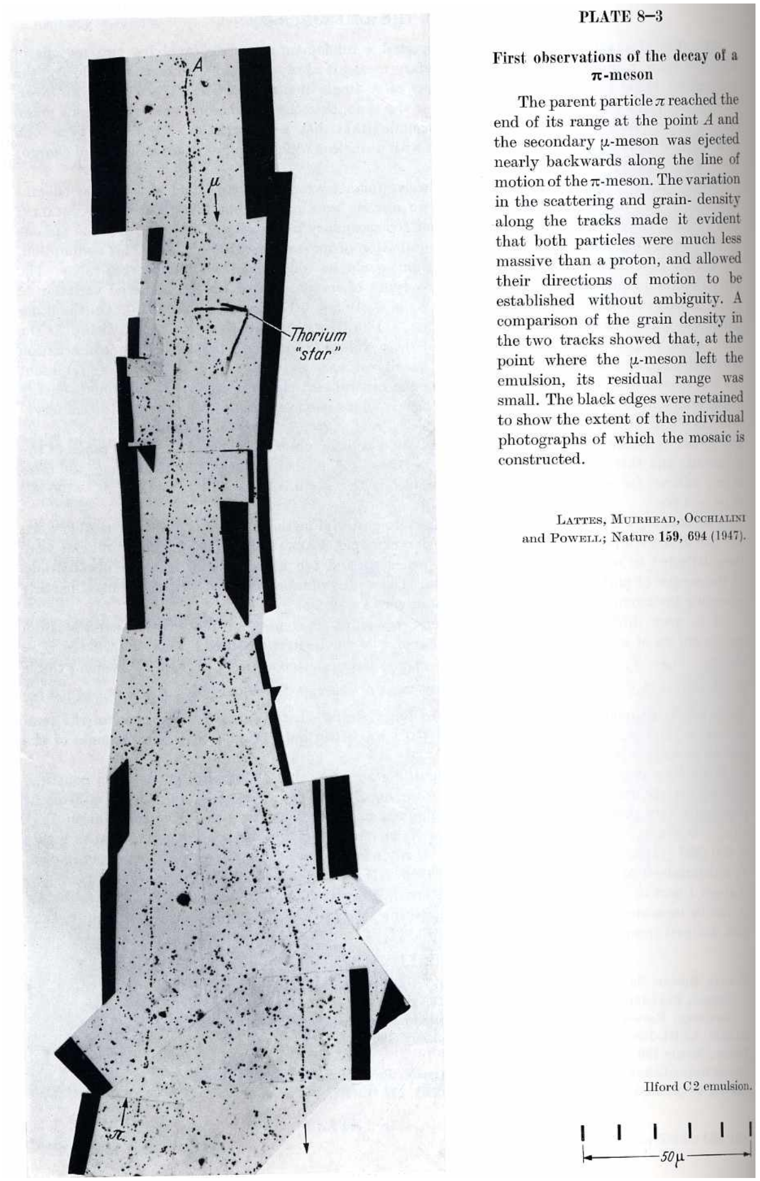


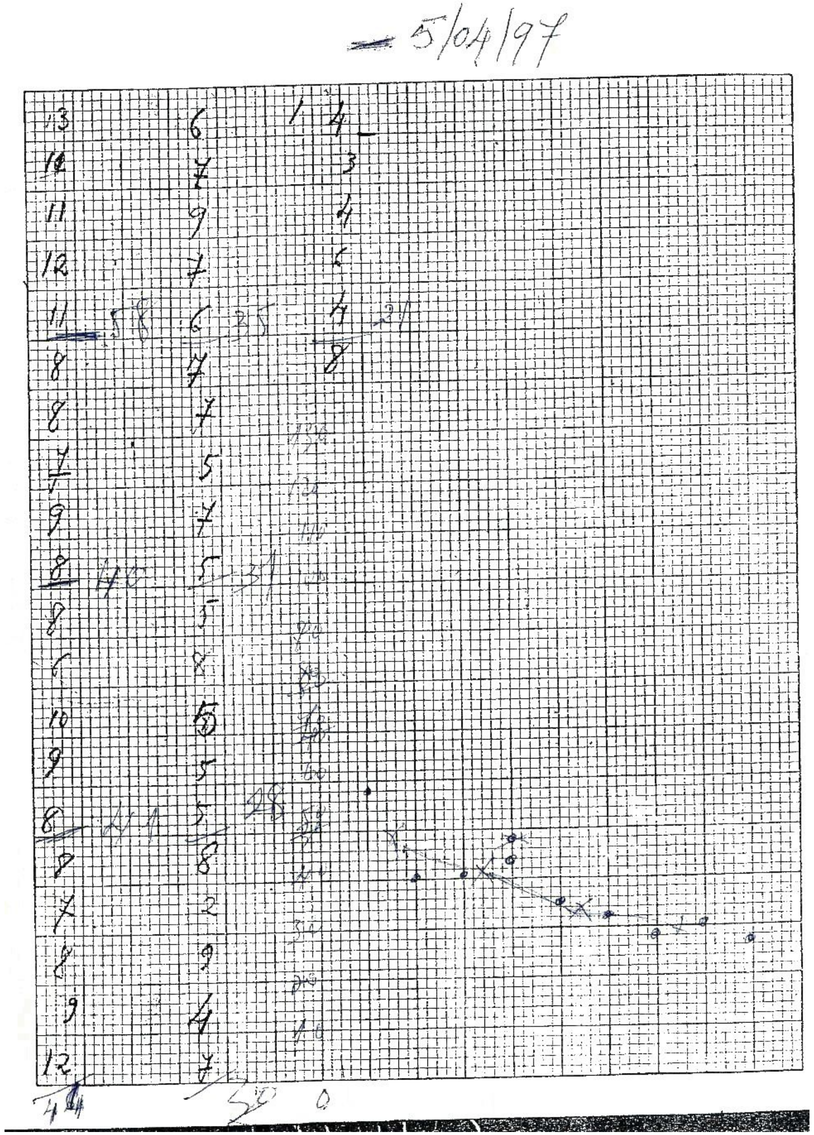
PLATE 8–3

First observations of the decay of a π-meson

The parent particle π reached the end of its range at the point A and the secondary μ-meson was ejected nearly backwards along the line of motion of the π-meson. The variation in the scattering and grain- density along the tracks made it evident that both particles were much less massive than a proton, and allowed their directions of motion to be established without ambiguity. A comparison of the grain density in the two tracks showed that, at the point where the μ-meson left the emulsion, its residual range was small. The black edges were retained to show the extent of the individual photographs of which the mosaic is constructed.

Lattes, Muirhead, Occhialini and Powell; Nature 159, 694 (1947).

Ilford C2 emulsion.



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Introduction

- First complete π−μ decay observed at Pyrénées

PLATE 8–4

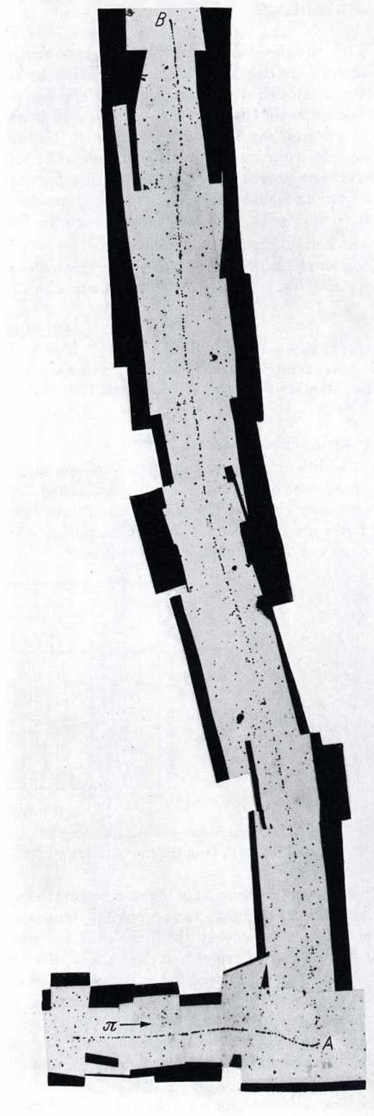
First observations of the decay of a π-meson

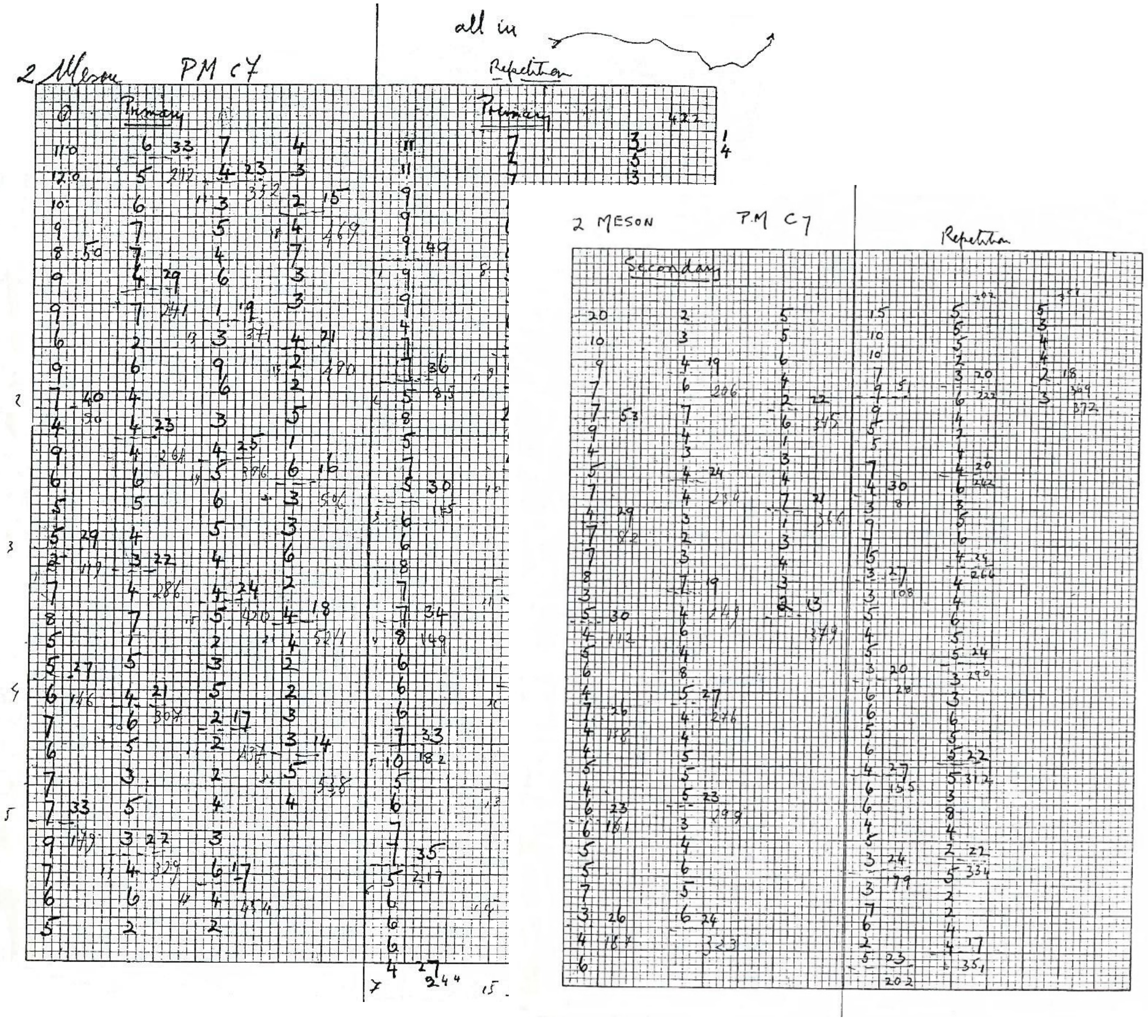
This second example of the decay of a π-meson was found shortly after the first. Although the track of the parent particle is short, it gives unambiguous evidence for the direction of motion of the particle and for its low mass. The secondary μ-meson came to rest in the emulsion, its range being 610 μ.

LATTES, MUIRHEAD, OCCHIALINI and POWELL; Nature **159**, 694 (1947).

Ilford C2 emulsion.

50μ





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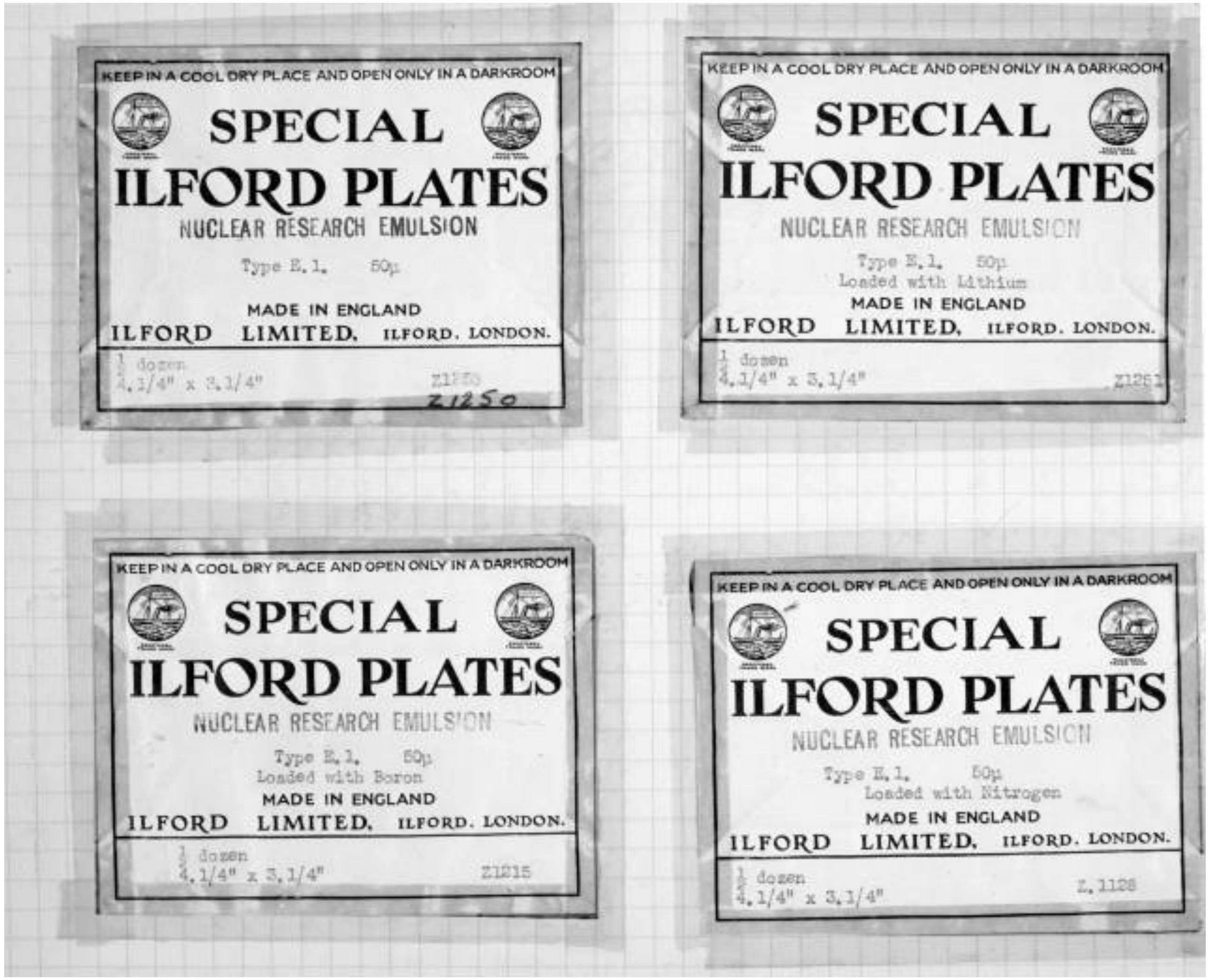
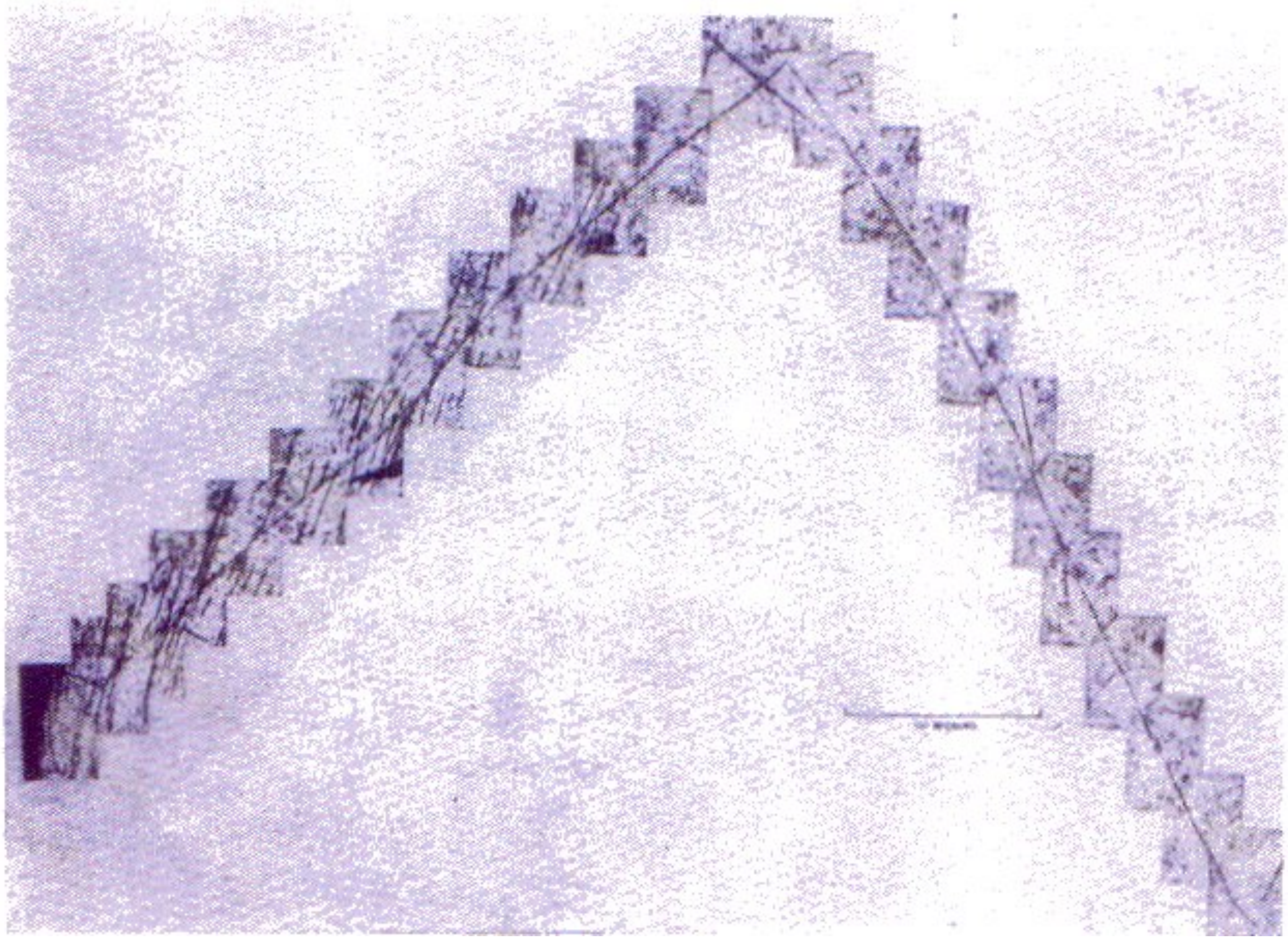
Sorte ao observar o decaimento em películas de 50 μ



Introduction

π^+ observed at Berkeley, using Ilford C2 emulsion plate

FIG. 5. Disintegration of a heavy positive meson to give a secondary. Photomicrograph made from Ilford C 2 plate. The heavy tracks on the left-hand side of the photomicrograph are due to protons from the target. They are often the most troublesome part of the background.



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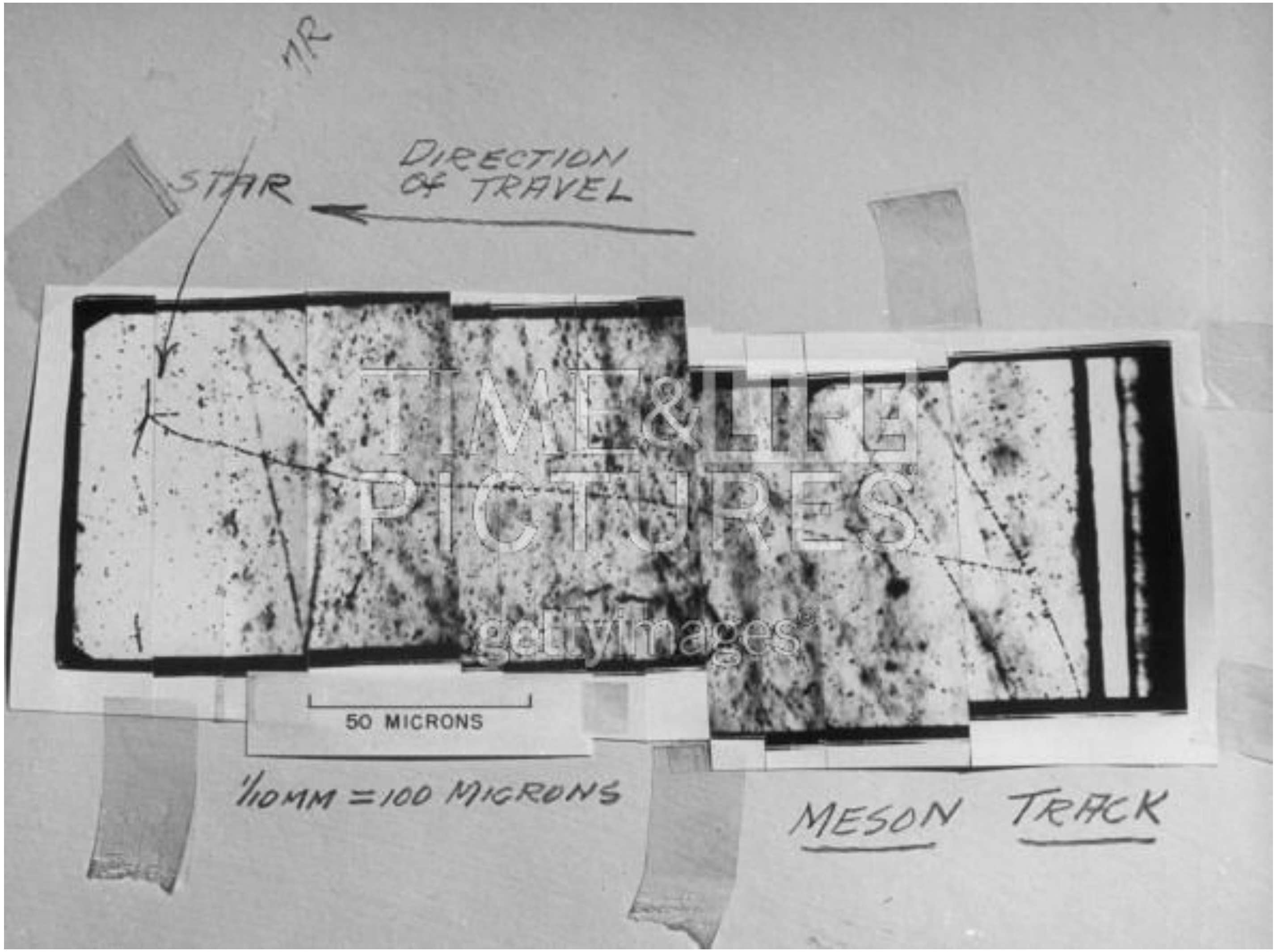
Introduction

π^- observed at Berkeley, using Ilford C2 emulsion plate



Introduction

- Multiple Meson Production

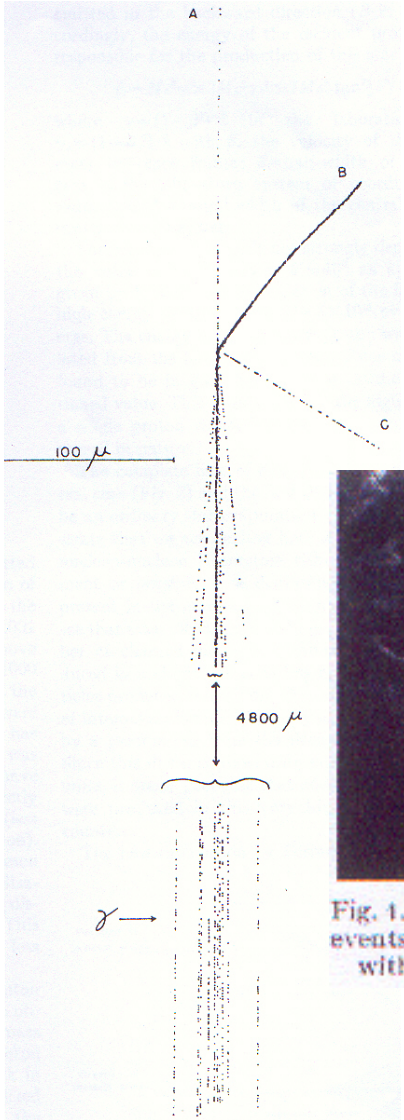


FIG. 1. Microprojection drawing of a high energy star produced by a 3×10¹³-ev proton.

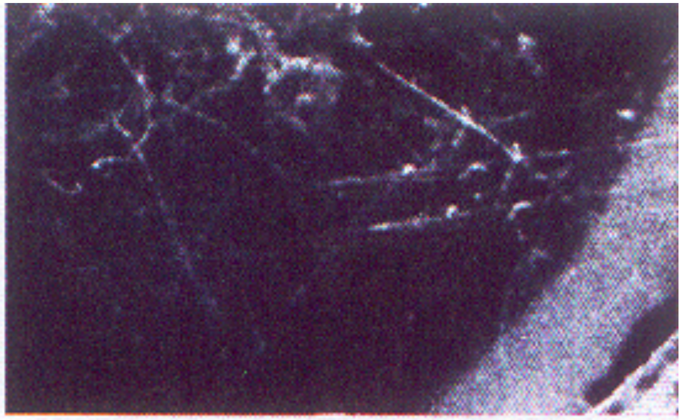
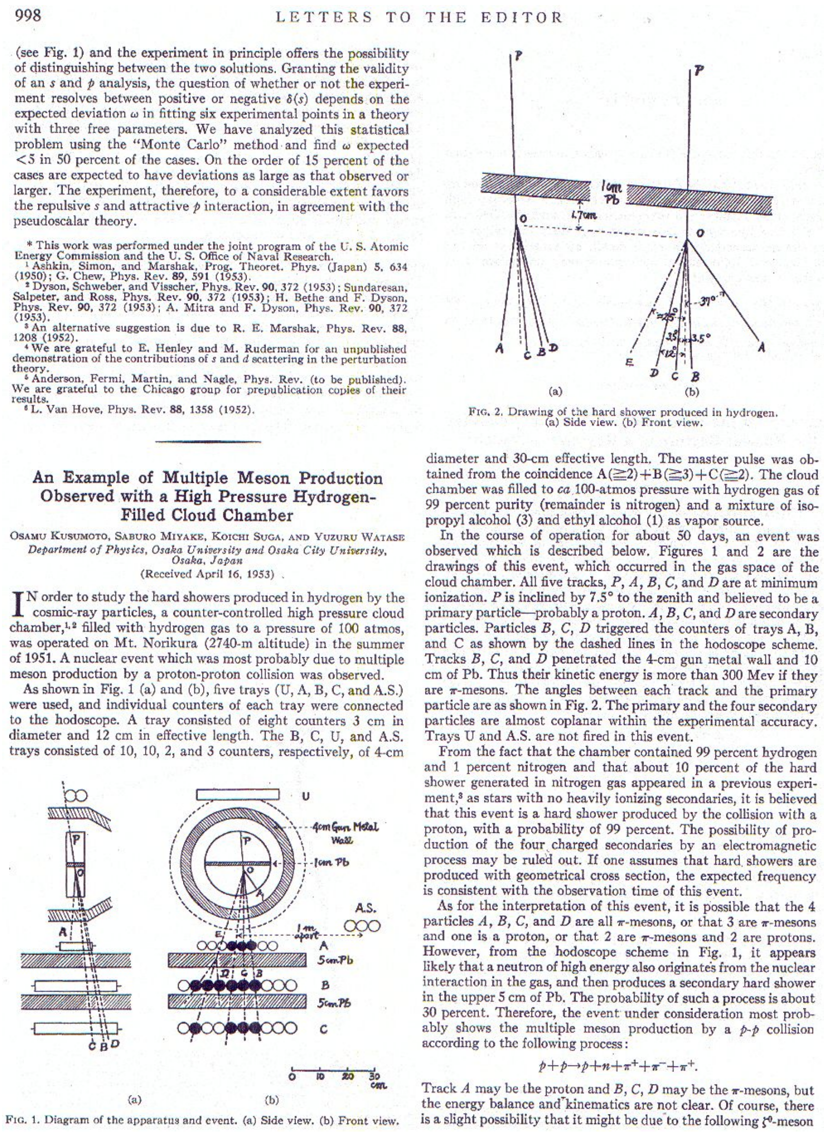


Fig. 1. The first photograph of multiple production events observed in a high-pressure cloud chamber filled with hydrogen gas (Osaka City University group).



(see Fig. 1) and the experiment in principle offers the possibility of distinguishing between the two solutions. Granting the validity of an *s* and *p* analysis, the question of whether or not the experiment resolves between positive or negative $\delta(s)$ depends on the expected deviation ω in fitting six experimental points in a theory with three free parameters. We have analyzed this statistical problem using the "Monte Carlo" method and find ω expected <5 in 50 percent of the cases. On the order of 15 percent of the cases are expected to have deviations as large as that observed or larger. The experiment, therefore, to a considerable extent favors the repulsive *s* and attractive *p* interaction, in agreement with the pseudoscalar theory.

* This work was performed under the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

[1] Ashkin, Simon, and Marshak, Prog. Theoret. Phys. (Japan) 5, 634 (1950); G. Chew, Phys. Rev. 89, 591 (1953).
[2] Dyson, Schweber, and Visscher, Phys. Rev. 90, 372 (1953); Sundaresan, Salpeter, and Ross, Phys. Rev. 90, 372 (1953); H. Bethe and F. Dyson, Phys. Rev. 90, 372 (1953); A. Mitra and F. Dyson, Phys. Rev. 90, 372 (1953).
[3] An alternative suggestion is due to R. E. Marshak, Phys. Rev. 88, 1208 (1952).
[4] We are grateful to E. Henley and M. Ruderman for an unpublished demonstration of the contributions of *s* and *d* scattering in the perturbation theory.
[5] Anderson, Fermi, Martin, and Nagle, Phys. Rev. (to be published). We are grateful to the Chicago group for prepublication copies of their results.
[6] L. Van Hove, Phys. Rev. 88, 1358 (1952).

FIG. 2. Drawing of the hard shower produced in hydrogen. (a) Side view. (b) Front view.

An Example of Multiple Meson Production Observed with a High Pressure Hydrogen-Filled Cloud Chamber

OSAMU KUSUMOTO, SABURO MIYAKE, KOICHI SUGA, AND YUZURU WATASE
Department of Physics, Osaka University and Osaka City University, Osaka, Japan
(Received April 16, 1953)

IN order to study the hard showers produced in hydrogen by the cosmic-ray particles, a counter-controlled high pressure cloud chamber,[1,2] filled with hydrogen gas to a pressure of 100 atmos, was operated on Mt. Norikura (2740-m altitude) in the summer of 1951. A nuclear event which was most probably due to multiple meson production by a proton-proton collision was observed.

As shown in Fig. 1 (a) and (b), five trays (U, A, B, C, and A.S.) were used, and individual counters of each tray were connected to the hodoscope. A tray consisted of eight counters 3 cm in diameter and 12 cm in effective length. The B, C, U, and A.S. trays consisted of 10, 10, 2, and 3 counters, respectively, of 4-cm diameter and 30-cm effective length. The master pulse was obtained from the coincidence $A(\geqq 2)+B(\geqq 3)+C(\geqq 2)$. The cloud chamber was filled to *ca* 100-atmos pressure with hydrogen gas of 99 percent purity (remainder is nitrogen) and a mixture of isopropyl alcohol (3) and ethyl alcohol (1) as vapor source.

FIG. 1. Diagram of the apparatus and event. (a) Side view. (b) Front view.

In the course of operation for about 50 days, an event was observed which is described below. Figures 1 and 2 are the drawings of this event, which occurred in the gas space of the cloud chamber. All five tracks, *P*, *A*, *B*, *C*, and *D* are at minimum ionization. *P* is inclined by 7.5° to the zenith and believed to be a primary particle—probably a proton. *A*, *B*, *C*, and *D* are secondary particles. Particles *B*, *C*, *D* triggered the counters of trays A, B, and C as shown by the dashed lines in the hodoscope scheme. Tracks *B*, *C*, and *D* penetrated the 4-cm gun metal wall and 10 cm of Pb. Thus their kinetic energy is more than 300 Mev if they are π-mesons. The angles between each track and the primary particle are as shown in Fig. 2. The primary and the four secondary particles are almost coplanar within the experimental accuracy. Trays U and A.S. are not fired in this event.

From the fact that the chamber contained 99 percent hydrogen and 1 percent nitrogen and that about 10 percent of the hard shower generated in nitrogen gas appeared in a previous experiment,[3] as stars with no heavily ionizing secondaries, it is believed that this event is a hard shower produced by the collision with a proton, with a probability of 99 percent. The possibility of production of the four charged secondaries by an electromagnetic process may be ruled out. If one assumes that hard showers are produced with geometrical cross section, the expected frequency is consistent with the observation time of this event.

As for the interpretation of this event, it is possible that the 4 particles *A*, *B*, *C*, and *D* are all π-mesons, or that 3 are π-mesons and one is a proton, or that 2 are π-mesons and 2 are protons. However, from the hodoscope scheme in Fig. 1, it appears likely that a neutron of high energy also originates from the nuclear interaction in the gas, and then produces a secondary hard shower in the upper 5 cm of Pb. The probability of such a process is about 30 percent. Therefore, the event under consideration most probably shows the multiple meson production by a p-p collision according to the following process:

$$p+p\rightarrow p+n+\pi^{+}+\pi^{-}+\pi^{+}.$$

Track *A* may be the proton and *B*, *C*, *D* may be the π-mesons, but the energy balance and kinematics are not clear. Of course, there is a slight possibility that it might be due to the following ζ^0-meson

Introduction

- Jets

'Jets' due to the nuclear collision of 200 BeV and 300 BeV protons

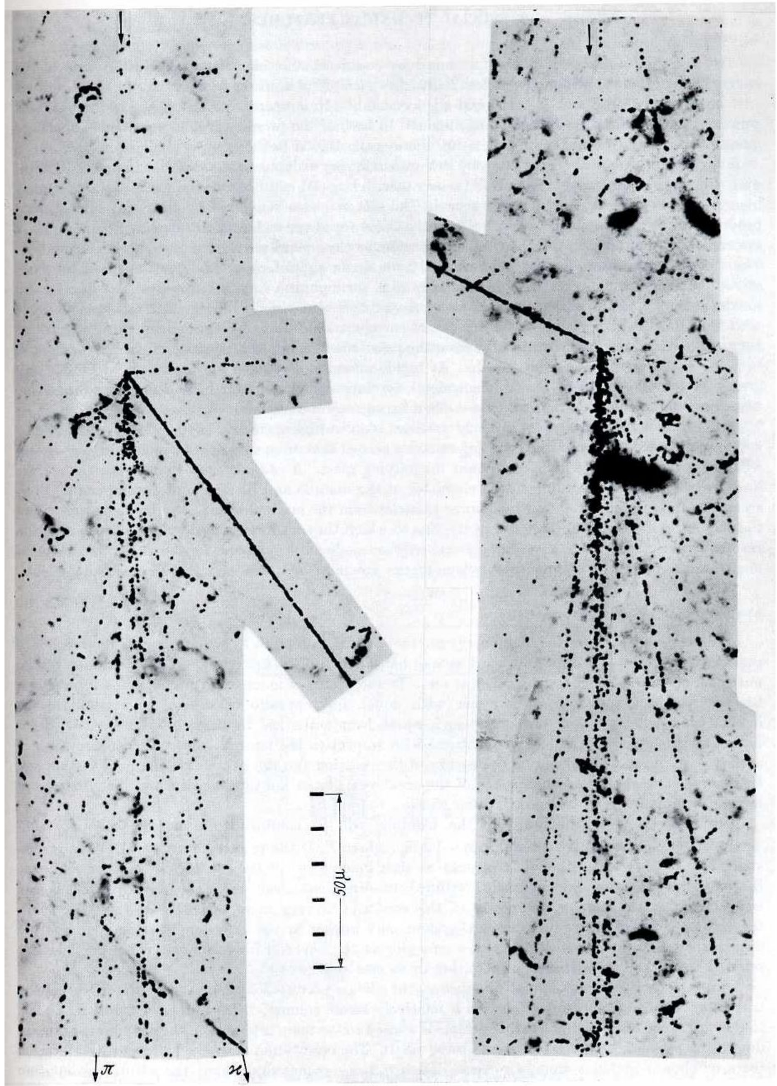
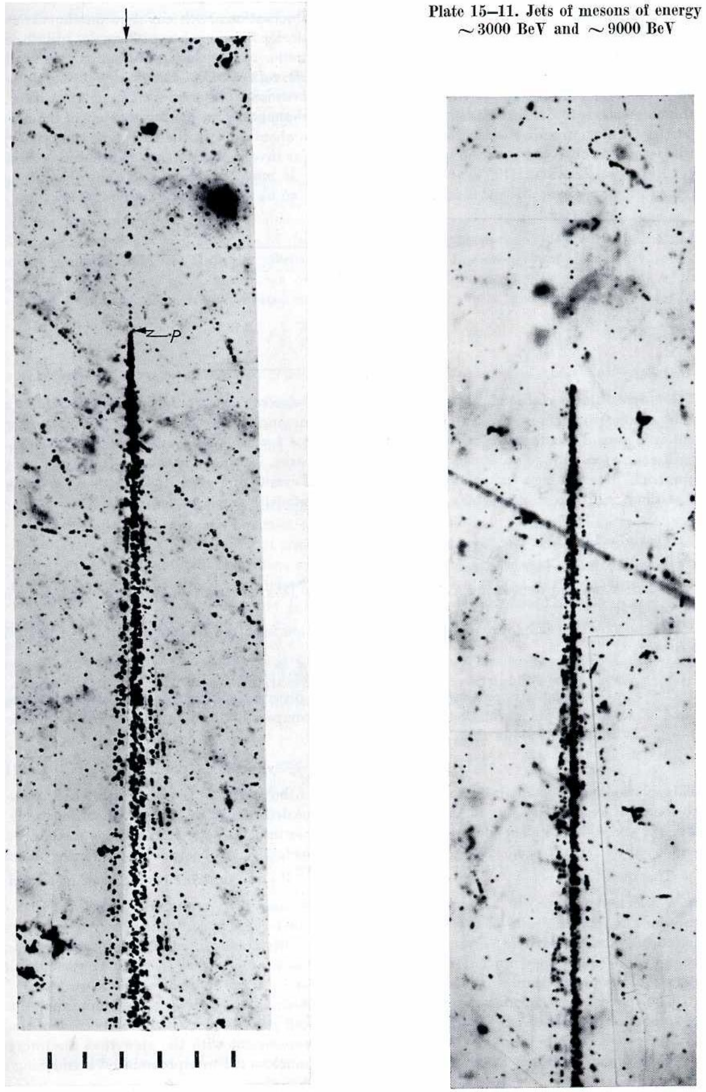


PLATE 15–2

Ilford G 5 emulsion. DANIEL, DAVIES, MULVEY and PERKINS (1952).

Plate 15–11. Jets of mesons of energy ~3000 BeV and ~9000 BeV



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Introduction

- Especulations for Multiple Particle Production

358 ACADÉMIE DES SCIENCES.

PHYSIQUE THÉORIQUE. — *Sur l'indétermination dans l'espace des moments et l'origine des gerbes à explosion.* Note (¹) de M. **Gleb Wataghin.**

Dans quelques Notes récentes (²) nous avons présenté les idées suivantes. Il existe une nouvelle espèce d'indétermination dans l'espace des moments, correspondant aux limitations de nos possibilités de mesure des impulsions, ces limitations dérivant de la nature des *forces de rayonnement* β. Il est possible de formuler cette indétermination au moyen d'une nouvelle algèbre des états quantiques. Dans celle-ci, on substitue au système complet de fonctions propres des opérateurs $-ih(\partial/\partial x)$ de l'impulsion p (ondes planes) un nombre fini d'états quantiques représentés par d'autres fonctions qui ne sont pas en général orthogonales, mais qui, pour des valeurs de p inférieures à une valeur critique $h/\pi_0 = b = 137\,mc$, ne diffèrent que très peu des représentations ordinaires de la théorie quantique.

Ces états sont définis par rapport à des mesures faites avec des appareils en repos dans un système Lorentzien. Pour les valeurs de p, relatives à ce système, telles que $p > b$, un état quantique nouveau remplace tout un ensemble $n(p)$ des états quantiques ordinaires, qui apparaissent indiscernables à l'observateur Lorentzien. En se rappelant la corrélation entre les états quantiques et les cellules de phase, on peut dire que pour $p > b$ les cellules quantiques nouvelles s'obtiennent par fusion d'un nombre n des cellules ordinaires contiguës, ce nombre $n(p)$ étant l'inverse du *facteur de convergence* $G(p)$. Dans l'intervalle $(p, p+dp)$ il y a $dz = (8\pi/c^3)V.G(p)p^2dp$ états quantiques nouveaux.

L'invariance relativistique se trouve satisfaite si l'on introduit dans le formalisme de l'électrodynamique (relativistique) des opérateurs qui dépendent des modules invariants des différences de deux 4-vecteurs p et si l'on attribue la non-orthogonalité des états et leur indétermination à la nature de l'interaction entre les corpuscules observés et les appareils de mesure liés au système de référence employé. « Il existe toujours dans le dispositif des mesures une partie d'un appareil qui constitue le système de référence proprement dit (par exemple dans le cas du γ-microscope c'est le diaphragme de l'objectif qui détermine la diffraction). Une analyse

(¹) Séance du 20 juin 1938.

(²) *Boletim da Faculdade de Filòsofia da Universidade de S. Paulo*, 1, 1938, p. 31; *R. Acc. Lincei* (en cours de publication).

repos fonction de l'énergie.

Examinons le mécanisme probable d'une gerbe à explosion : deux corpuscules se choquent et produisent plusieurs corpuscules secondaires (si dans le système de référence lié au centre de gravité leurs p sont ... des états non-orthogonaux ψ, ... à dans le premier ordre la pro-

38 Georg Pfotzer,

Z. Physik, 107 23 (1936)

vor 80 mm einstellt. (Man findet so für den Aufstieg am 2. November 1935: $t_z = 5{,}9 \cdot 10^{-5}$ und für die Abstiege am 12. August 1935 bzw. am 2. November

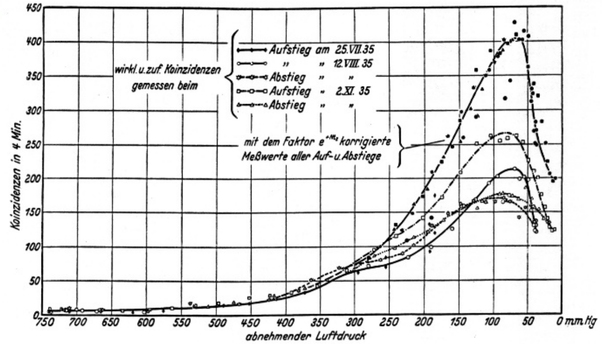


Fig. 10. Direkte Meßwerte der Auf- und Abstiege (untere Kurven) und unter Berücksichtigung der Ansprechwahrscheinlichkeit reduzierte Werte (obere Kurve).

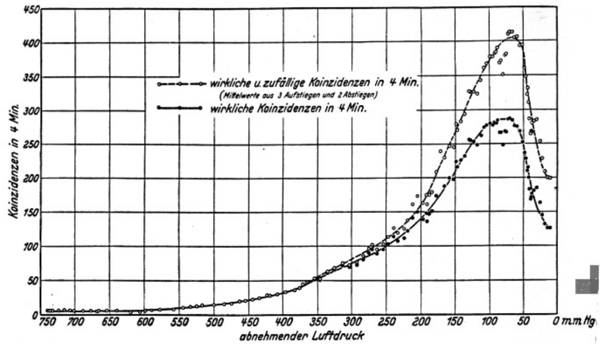
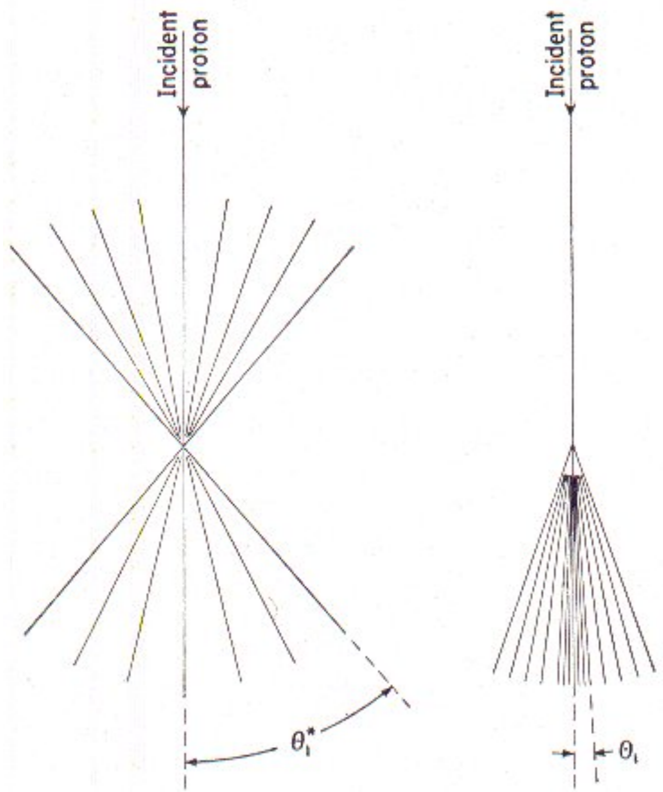


Fig. 11. Gemittelte Werte der zuf. + wirkl. Koinzidenzen aller Meßreihen (obere Kurve) und endgültige Kurve der wirklichen Koinzidenzen aus vertikaler Richtung (untere Kurve).

Models of Multiple Meson Production

The models should cover characteristics of jets

- Observation of shower particles distributed in a inner and outer cones, that implies in a quite strongly forward-backward assymetry in a center of mass system.



$$\tan\,\theta_1 = \sqrt{\frac{2Mc^2}{U}}\,\tan\left(\frac{\theta_1{}^*}{2}\right)$$

Models of Multiple Meson Production

The models should cover characteristics of jets

- Hadronic interaction is not completely inelastic, beeing inelasticity coeficient around 0.5 on average.
- Multiplicity increases very slowly with incident energy. Some recent dependences assumes

$$N \propto \ln\left(\sqrt{s}\right)$$

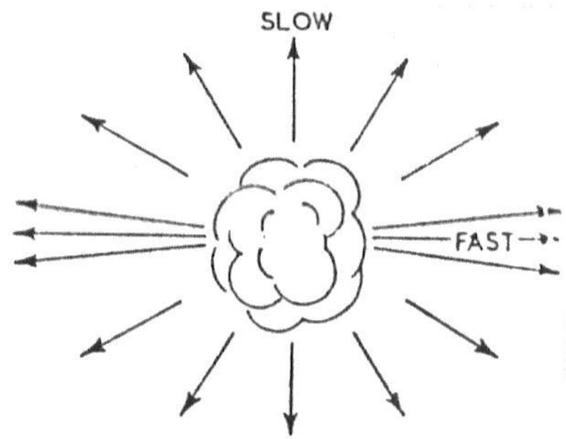
- The fraction of energy in π-meson decreases with incident energy, that is other particles like Kaon is produced

Models of Multiple Meson Production

- Wataghin's model (1936, 1941-1943) predicts a strong multiplicity dependence, $N \sim E^{1/2}$. Introduced the concept of cutoff (fire-ball) to remove the ultra-violet divergences in the field theory.

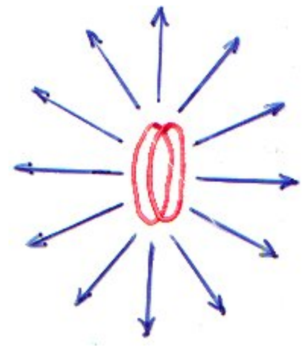
- L.O.W.'s model (1947) also predicts still too much high multiplictiy dependence, $N \sim E^{1/3}$

- Heisenberg's model (1952) predicts same dependence as Wataghin's, but shows assymetry.

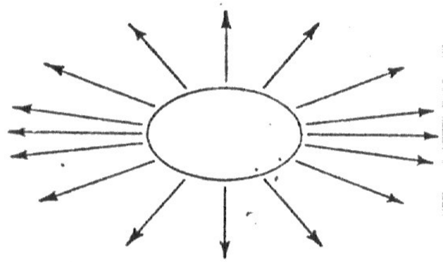


Models of Multiple Meson Production

- Fermi's model (1950-1954) predicts multiplicity dependence like $N \sim E^{1/4}$, but doesn't show pronounced assymetry and inelasticity is close to 1.

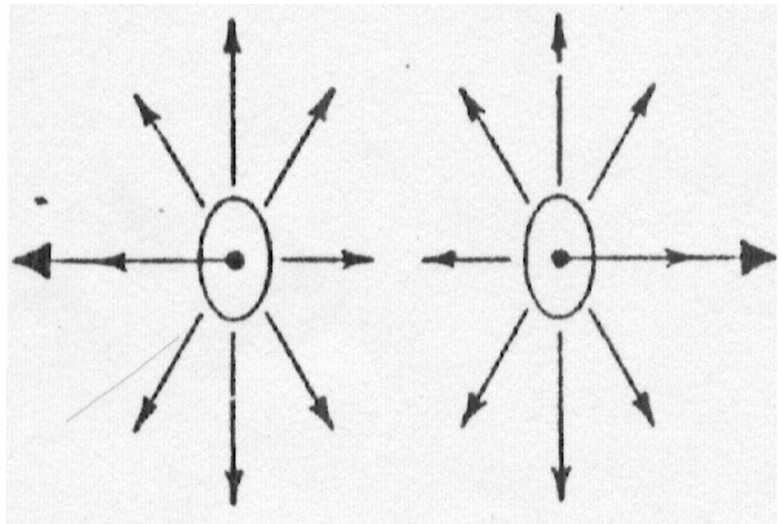


- Landau's model (1953), using hydrodynamical considerations, shows forward-backward assymetry, multiplicity dependence like $N \sim E^{1/4}$, a reasonable K/π ratio, but high inelasticity value. An important constancy of Transverse Momentum



Models of Multiple Meson Production

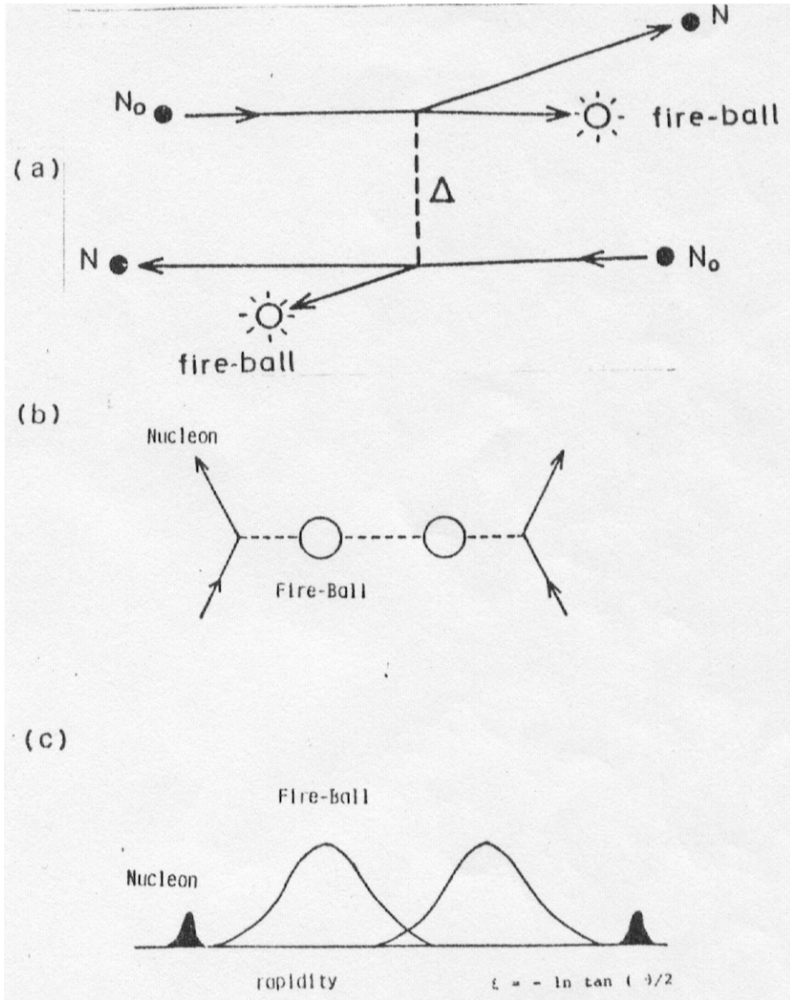
- Models for Multiple Meson Production with more than 1 emitting centers
- Takagi's (1952) and Kraushaar & Marks's (1954) model. A intrinsic difficulty is the assumption of the emission of mesons by a excited nucleons, assumption that seems not reasonable in view of collision and emission time considerations and inelasticity measurements



Models of Multiple Meson Production

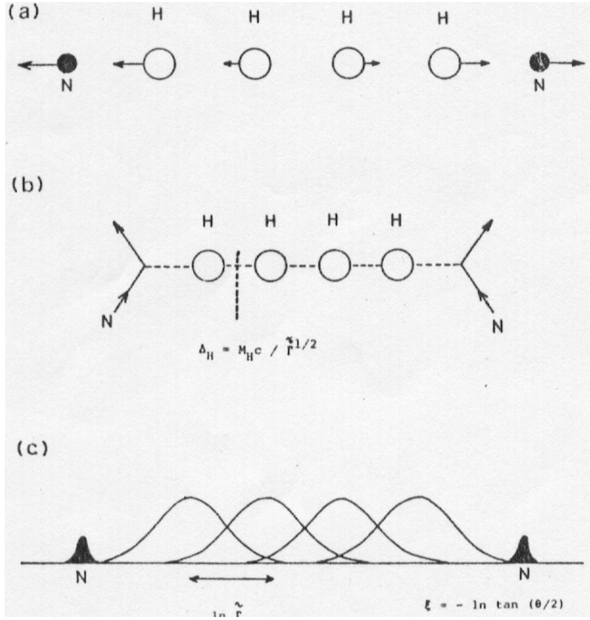
- Ciok’s (1958), Niu’s (1958), Cocconi’s (1958) models
- Niu’s two fire-ball model
- Where the four-momentum
  $\Delta \sim$ (1-2) GeV/c $\sim M_N c$
- a) Ilustration
- b) Diagram
- c) log tgθ –plot (pseudo
- rapidity)

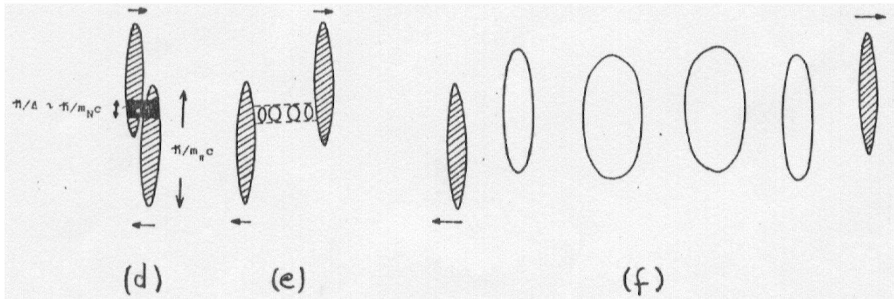
- In the Cocconi’s paper it
  appears the citation
  TWO FIRE-BALLS



Models of Multiple Meson Production

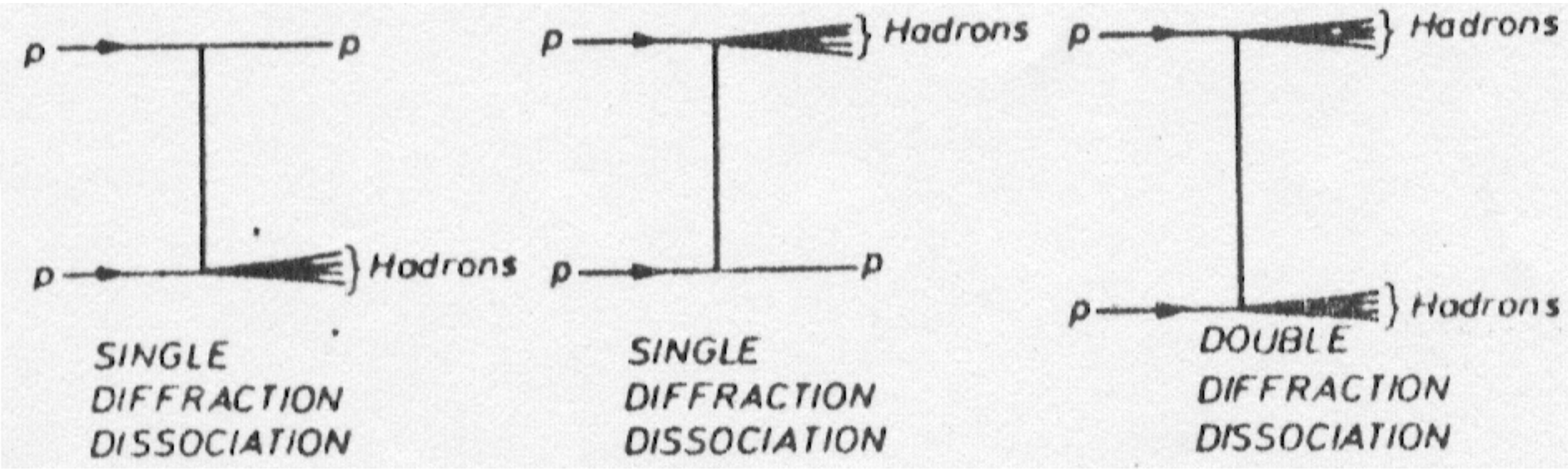
- Hasegawa’s H-quantum model (1961)
- analogy with black-body radiation.
- one motivation was from a
  composite theory of hadrons,
  mainly Sakata’s model.





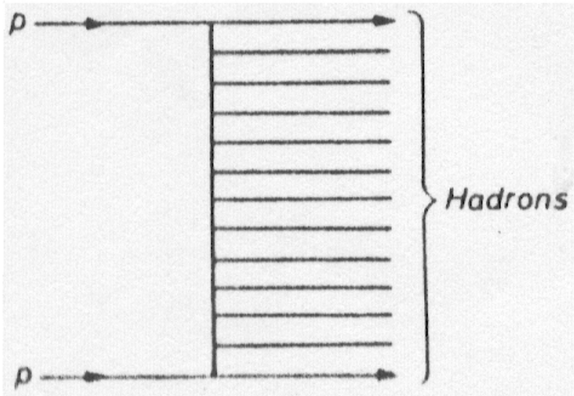
Models of Multiple Meson Production

- Feinberg's diffraction dissociation model (1956)
- analogy with Optics
- this proccess could be either elastic and inelastic

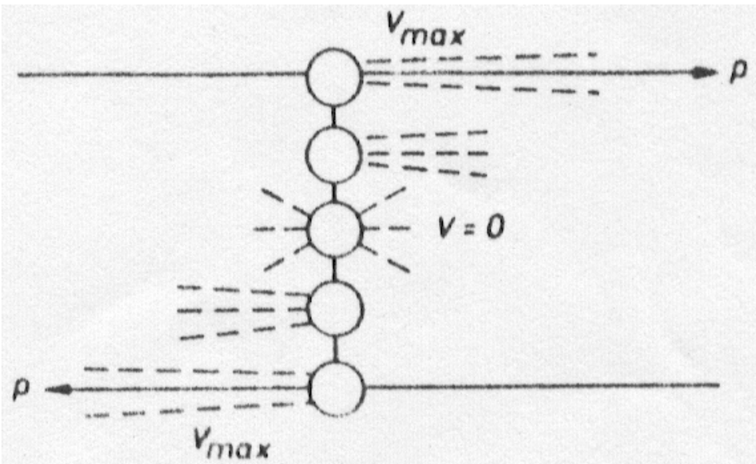


Models of Multiple Meson Production

- Berestezky & Pomeranchuk’s model (1960)
- A.F.S.T., Multiperipheral’s model (1961)

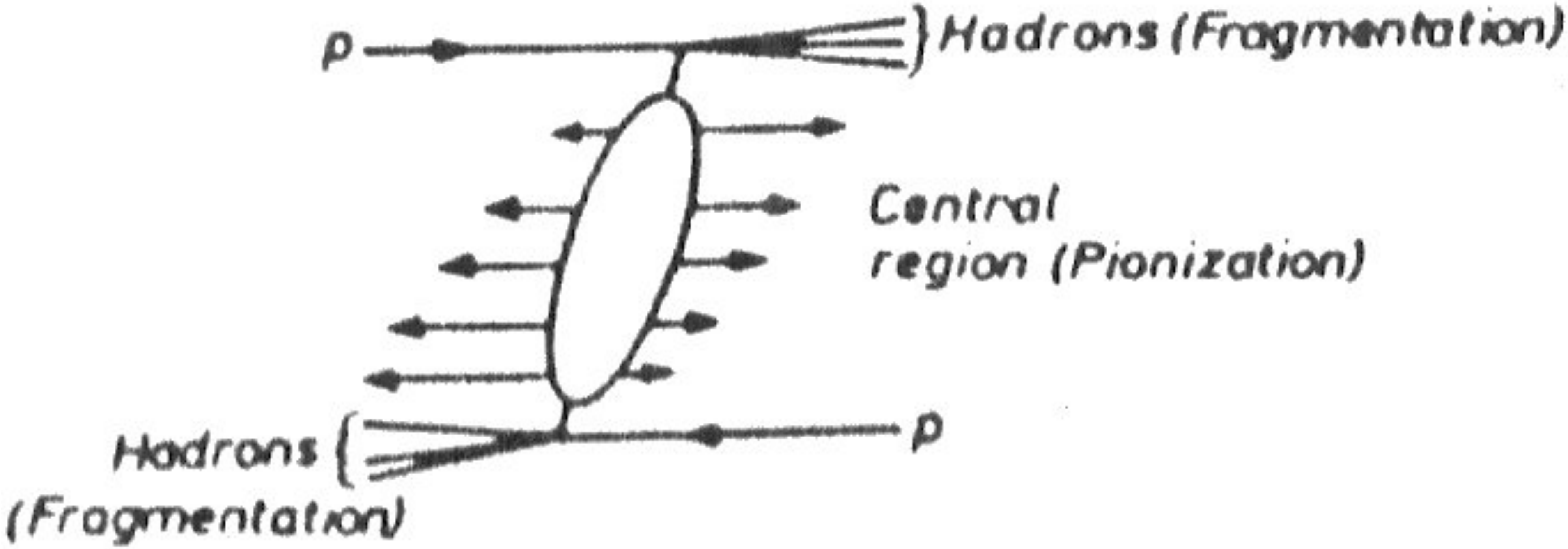


- Hagedorn, Statistical thermodynamical’s model (1965)



Models of Multiple Meson Production

- Benecke, Chou,Yang & Yen, limiting fragmentation's model (1969)



Models of Multiple Meson Production

- Models for Multiple Meson Production at the level of particles constituents.
- Gell-Mann quark's model (1964). He mention that a formal mathematical model based on field theory can be buid up for the quarks (u,d,s) exactly as for (p,n,λ) in the old Sakata model (1956). Also he mention a Symmetrical Sakata model and Unitary Symmetry. Nowadays there are more 3 quarks (c,b,t).
- Feynman parton's model (1969). From inelastic high energy electron scattering results, he extended a pointlike structure to the hadrons.
- Quark-parton model. Identifying parton as a quark, an extended model assumes nucleons composed of a core of partons plus additional valence partons and the field quanta is called gluon.

Models of Multiple Meson Production

- Our (BJ Collaboration) attempts

- Empirical formulation of rapidity density distribution in multiple particle production in a wide energy range from fixed target to LHC, Akinori Ohsawa et all. – J.Phys.G:Nucl.Part.Physics37(2010)075003

- Description of (Pseudo) Rapidity Density and Transverse Momentum Distribution in a Wide Energy Range (root s=22.4-7000 GeV), Akinori Ohsawa et all. – Int.Jornal of Modern Phys.A27, 9(2012)1250043

- We refer to: A nonextensive thermodynamical equilibrium approach in e^+e^- → hadrons, I.Bediaga et. all. – Physica A286(2000),156-163 which in turn uses the so called Tsallis Statistics in Possible Generalization of Boltzmann-Gibbs Statistics, C.Tsallis, Journal of Statistical Physics, vol.52, Nos.1/2, (1988), 479-487. That means that it are attempts for Thermodynamical Models

Cosmic Rays - Accelerator

- E.L.Feinberg wrote

As a result a deep gap appeared between accelerator and cosmic ray physicists as far as objects of investigation, data, methods of treating the experiment, and dominating ideas are concerned. Some theoretic-model approaches used long ago in cosmic rays are now proposed as new ones. The regularities established on accelerators for low multiplicity and low energy events are transferred without any hesitation to high ($n \gtrsim \langle n \rangle$) multiplicity and very high energy processes where they are often not valid, and so on. Therefore an attempt to review the situation in the spirit of bridging over this gap seems to be desirable even if the result is imperfect*.

*As an example of harm caused by this gap we can quote the two year history of development and experimental test of the Feynman idea of scaling. Both, theorists and experimenters, neglecting the facts established in cosmic rays, actually confined themselves to treatment of merely a small (~ 20%) part of particles, which are produced in a hadron collision and constitute the so called leading or "isobaric" component. They left aside the main bulk of particles, – the "pionization" ones, having (at $E_L \lesssim 10^3$ GeV) average CMS energy below ~ 1 GeV. For the first component the validity of scaling was triumphantly proved. From the point of view of cosmic ray physics in the $E_L \lesssim 10^3$ GeV interval this was almost trivial, and the value of this proof is essentially in incomparably higher precision and refinement. On the other hand the main, second component was neglected (even a purposely planned and done experiment on ISR [141], see fig. 53, did not take it into account). The present paper had been already completed when the information concerning many very important new CERN ISR experiments [175–179] arrived. These experiments clearly show violation of scaling for the main bulk of produced particles until $E_L \sim 500–1000$ GeV and thus support the suggestion which had arisen from cosmic ray studies.

High Energy Interactions

- What's about B-J Collaboration data under particles constituents analysis?
- This was done by Toru Shibata (Forward hard scattering in hadron-hadron collisions in the energy region ~10^{14} eV, Phys.Rev.22,No.1,100-120, (13 December 1979).

- In the photo Toru Shibata
- at center, Yoichi Fujimoto
- (left) and Andrea Wataghin
- at rear right

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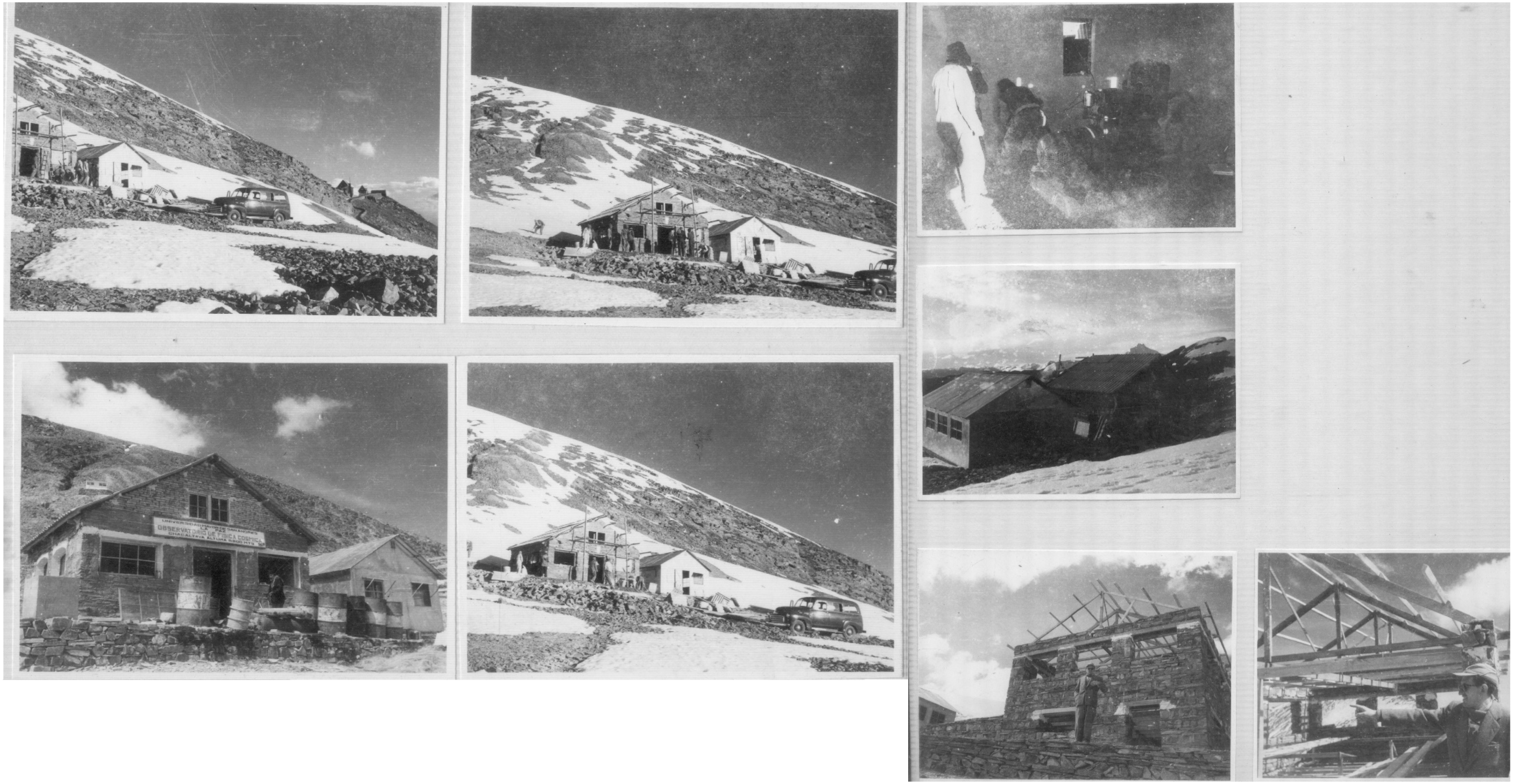
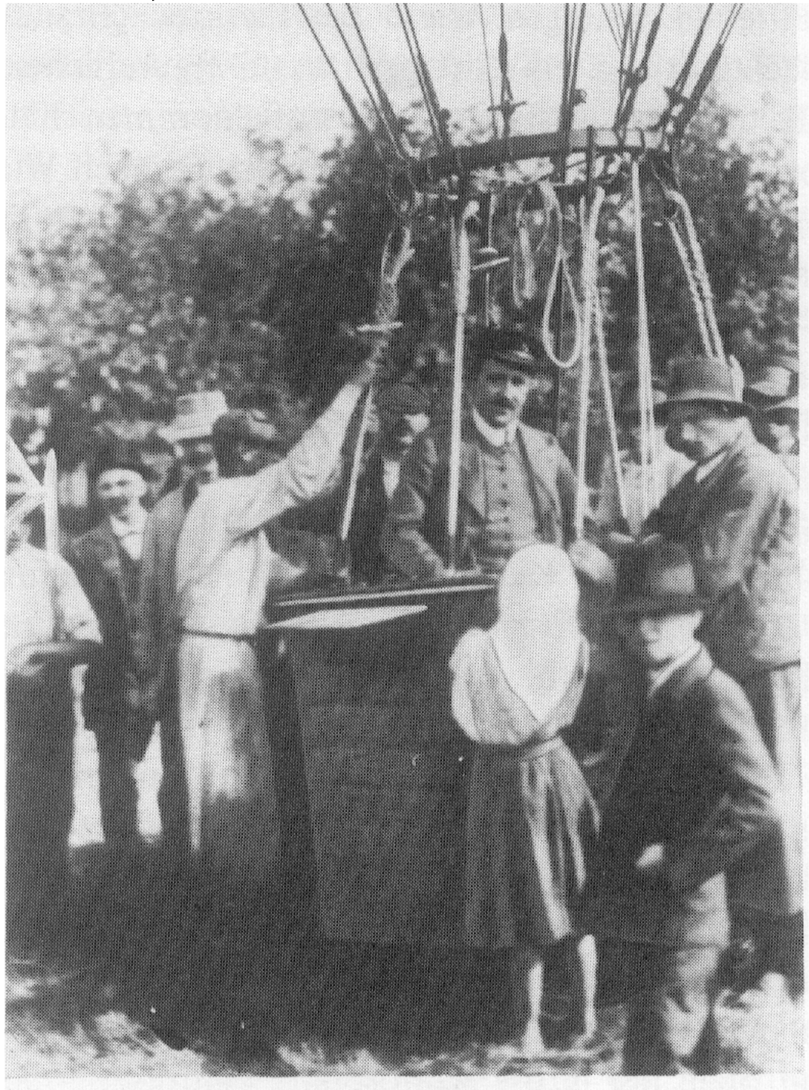
1949: Centro Brasileiro de Pesquisas Físicas
1952: Laboratório de Física Cósmica de Chacaltaya



Monte Chacaltaya (~ 1952). At the top, the place of $\pi-\mu$ observation

Homage to obreros. The leader, Sr.Jose at the center

- At 6:12 a.m. of August 7, 1912, Victor Franz Hess ascended in a successful balloon flight till 5,350 m



Hess bei Ballonlandung (1912).

Almost 50 years after B-J Collaboration finished the exposure of the first two emulsion chambers at μ-meson building (From June,15 to August, 05), 1962

Construction & transportation of Emulsion Chamber

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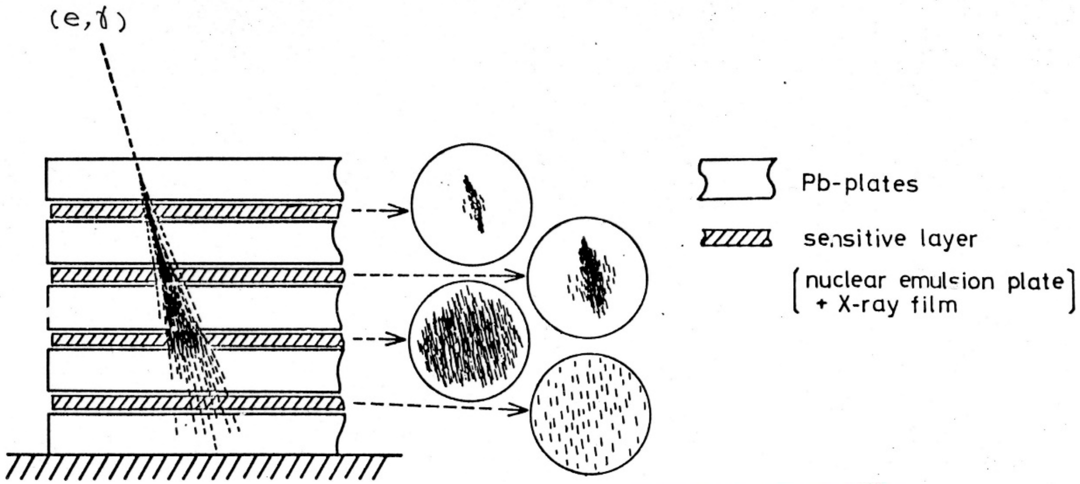
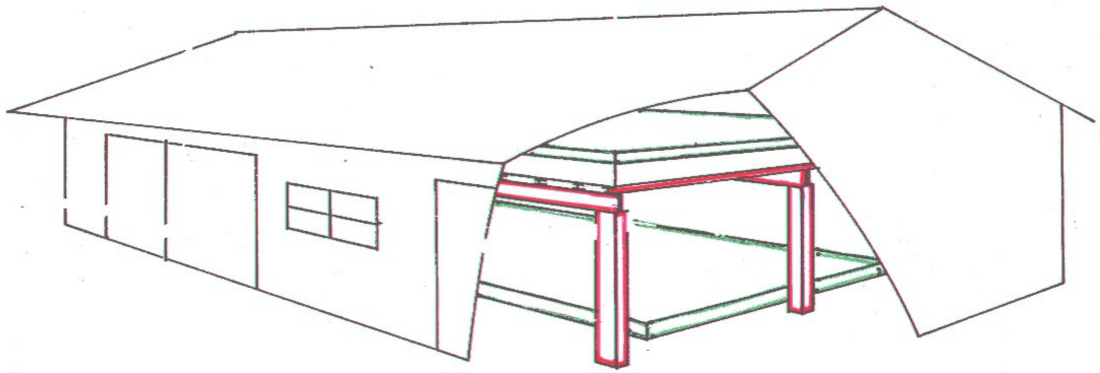
Emulsion Chamber

- Observations of Brazil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment





Fire-ball analysis by B-J Collaboration

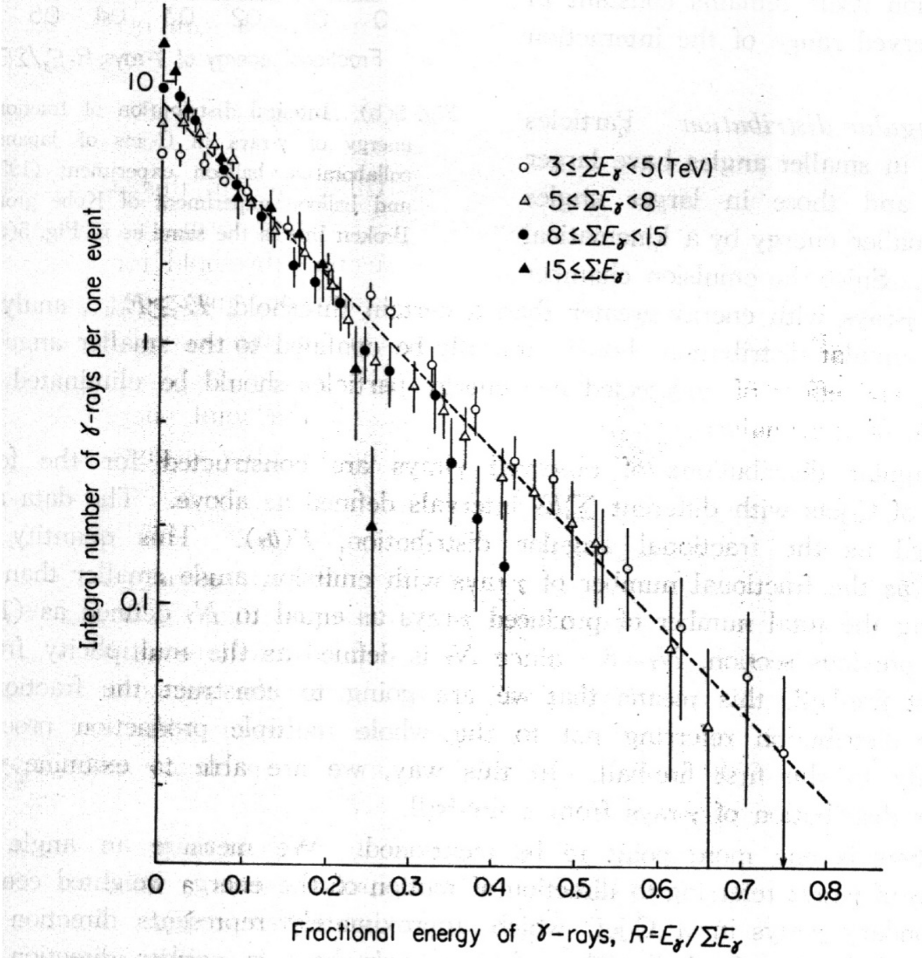


Fig. 5(a). Integral distribution of fractional energy, $R=E_\gamma/\sum E_\gamma$, of γ-rays in C-jets of Câmaras 12 and 13. Broken line shows an exponential distribution, $N_\gamma \exp(-N_\gamma E_\gamma/\sum E_\gamma)$ with $N_\gamma=8$ (see text).

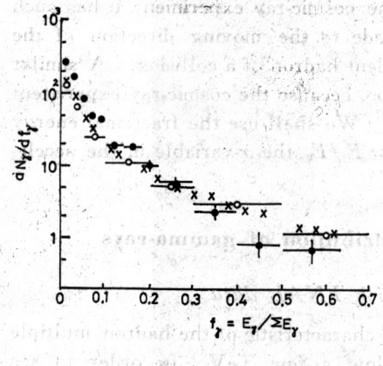


Fig. 7. Distribution of fractional energy $f_\gamma=E_\gamma/\sum E_\gamma$ of gamma-rays.
- ● 80 C-jets of Chacaltaya with $\sum E_\gamma>20$ TeV.
- ○ scaling simulation from 205 GeV proton collisions in bubble chamber.
- × scaling simulation from CERN ISR events.

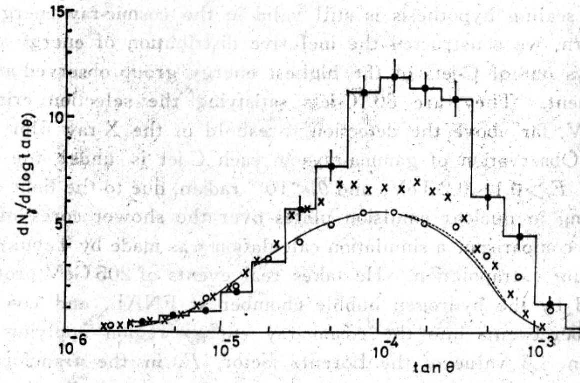
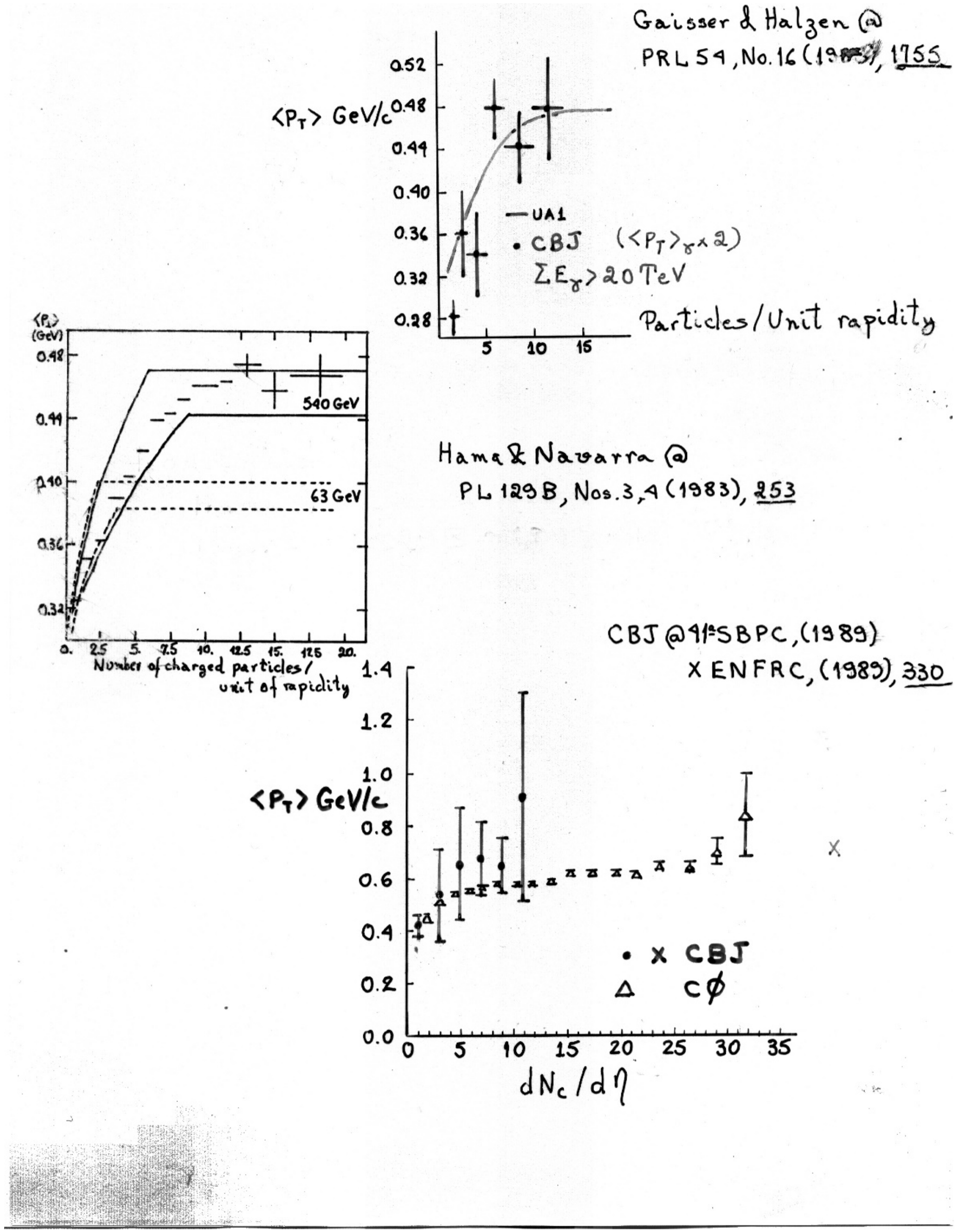


Fig. 8. Angular distribution of gamma-rays in logtanθ-scale.
- ● 80 C-jets of Chacaltaya with $\sum E_\gamma>20$ TeV.
- ○ scaling simulation from 205 GeV proton collisions in bubble chamber.
- × scaling simulation from CERN ISR events (—— ISR without successive interactions and - - - the same as above plus extended central plateau).

$\langle k_\gamma\rangle=0.29$ for the present emulsion chamber experiment. We will use a value of $\langle k_\gamma\rangle=0.3$ for the primary energy estimation hereafter, unless particularly stated.

3.2. *Test of scaling——Comparison with ISR data*

Comparisons (Acceleration – Cosmic Ray) data



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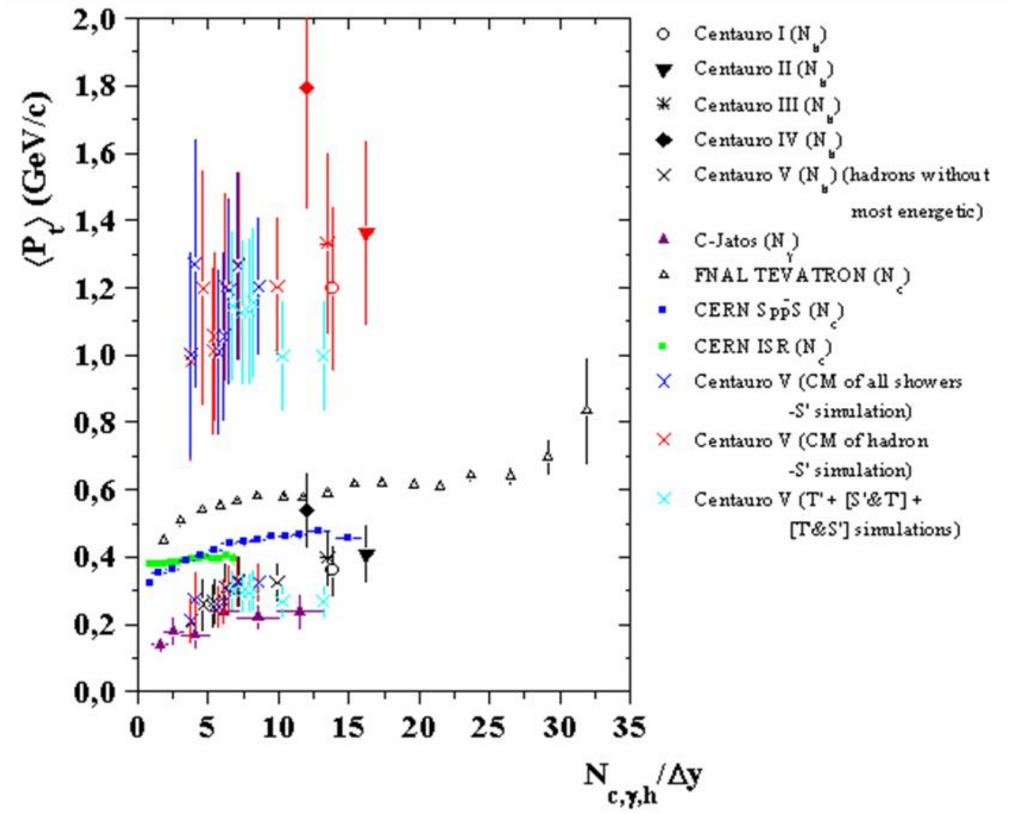
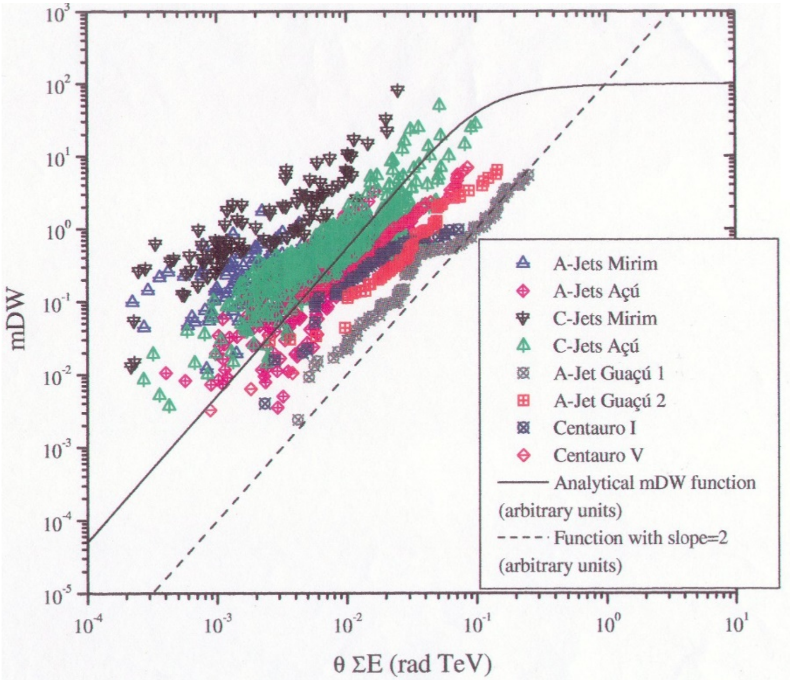
Fire-ball analysis of B-J Collaboration





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UA1/S$\bar{p}$pS

Expt.	: UA 1
Beam	: -
Approved	: 29.6.78
Status	: Preparation

A 4π SOLID ANGLE DETECTOR FOR THE SPS USED AS A PROTON-ANTIPROTON COLLIDER AT A CENTRE OF MASS ENERGY OF 540 GeV

Aachen[1]-Annecy (LAPP)[2]-Birmingham[3]-CERN[4]-Paris Collège de France[5]-Queen Mary College[6]-Riverside[7]-Rutherford[8]-Saclay (CEN)[9] Collaboration

A. Astbury[8], B. Aubert[2], A. Benvenuti[4], D. Bugg[6], A. Bussière[2], Ph. Catz[2], S. Cittolin[4], D. Cline*, M. Corden[3], J. Colas[2], M. Della Negra[2], L. Dobrzynski[5], J. Dowell[3], K. Eggert[1], E. Eisenhandler[6], B. Equer[5], H. Faissner[1], G. Fontaine[5], S.Y. Fung[7], J. Garvey[3], C. Ghesquière[5], W.R. Gibson[6], A. Grant[4], T. Hansl[1], H. Hoffmann[4], R.J. Homer[3], M. Jobes[3], P. Kalmus[6], I. Kenyon[3], A. Kernan[7], F. Lacava[4]**, J.Ph. Laugier[9], A. Leveque[9], D. Linglin[2], J. Mallet[9], T. McMahon[3], F. Muller[4], A. Norton[4], R.T. Poe[7], E. Radermacher[1], H. Reithler[1], A. Robertson[8], C. Rubbia[4], B. Sadoulet[4], G. Salvini[4]**, T. Shah[8], C. Sutton[8], M. Spiro[9], K. Sumorok[3], P. Watkins[3], J. Wilson[3], R. Wilson[4]***

$p\bar{p}$ collisions in the SPS open up an energy domain, in which new and fundamental phenomena should emerge. At $\sqrt{s}$ = 540 GeV and L ≃ 10^{30} cm^{-2} sec^{-1} the intermediate vector bosons and possibly the Higgs boson(s) should be produced in detectable quantities. Eventually new high-mass vector mesons and free quarks could be detected. At lower luminosities significant investigations can be carried out on quark-quark interactions through high p_T jets and Drell-Yan mechanism. Gluon interactions may be observed. In this new energy domain even "conventional" hadron physics takes on a renewed interest, especially in view of the possible change of régime suggested by cosmic-ray experiments.

The apparatus to study these phenomena will cover essentially all of the solid angle (down to 1°). The core of the apparatus is a conventional dipole magnet (7 kG) whose inner volume is occupied by a multiparticle detector, 6 m long and 1.3 m in radius, surrounded by a high-precision electromagnetic calorimeter. Hadron calorimetry is built inside the iron of the magnet, which also serves as a muon filter. In this way all the hadrons and charged leptons can be measured and electrons and muons distinguished from hadrons. The electron and hadron calorimeters provide selective triggers for W-search and jet studies.

* Visitor from University of Wisconsin, Madison, Wisconsin, USA.
** Visitor from University of Roma, INFN Roma, Italy.
*** Visitor from Harvard University, Cambridge, Mass., USA.

Reference:
SPSC/78-6/P 92

ence, shows a strong multiplicity dependence of the transverse momentum bution of charged particles produced in proton-antiproton collisions at 0 GeV. The effect is shown in Fig. 13. This figure shows that inclusive

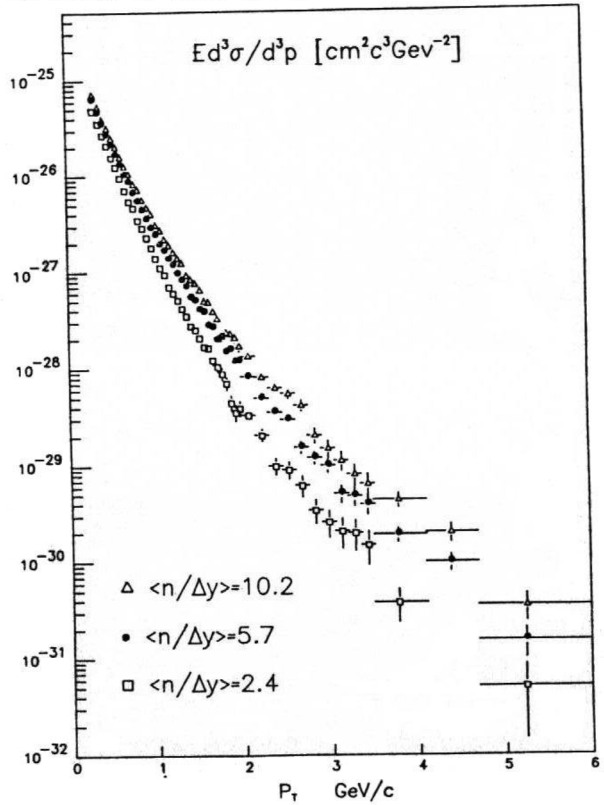


FIGURE 13
Inclusive p_t spectrum for different multiplicity densities.
UA1 Collaboration.

e particle spectra, when analysed in different multiplicity regions, exhibit ıttening of the cross-section with increasing multiplicity. This effect was ompletely unexpected. In fact, a correlation between transverse spectra and plicity has been observed in cosmic ray experiments[13]. The observation of c ray jets in emulsion chambers, in the region of primary energy 10÷1000 shows that jets are characterized by 3 distinct types of multiple pion ıction. In Fig. 14 we reproduce the observed γ-rays transverse momentum :ra for the three different type of jets in which one can divide the entire le[13]. In the figure we have also indicated the characteristic number of γ ınit rapidity interval. The broadening of the p_t-distribution with increasing

multiplicity is very evident, larger in fact than the effect observed at the collider. In Table I, we reproduce, from Ref. 13), the main characteristics of these events. For a comparison with collider data, we recall than $n_\gamma = 2n_{\pi^0} = n_{ch}$ and $\langle p_t \rangle_\gamma = \frac{1}{2} \langle p_t \rangle_{\pi^0}$. The difference between events in various multiplicity intervals has been studied using the fire-ball hypothesis. To date, it is not understood how much of the effect can be attributed to interaction of complex nuclei and how much is a genuine new phenomenon. One cannot but stress however the correlation between multiplicity and transverse spread of the produced pions: higher multiplicity events are characterized by flatter p_t distributions or, at high multiplicity, pions are produced at larger angles. It is the same effect, albeit not as large, which has been observed at the collider.

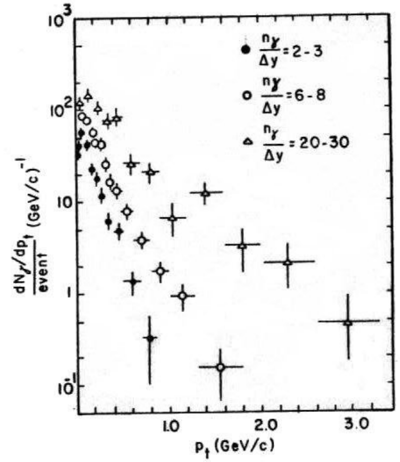


FIGURE 14
Transverse Momentum Distribution of γ-rays observed in cosmic ray events, for three types of jets; Mirim jets; açu jets; guaçu jets. Ref. 13).

TABLE I

type of jet	characteristics of produced gamma-produced rays: $\langle p_t \rangle$	characteristics of produced gamma-produced rays: n_γ per unit rapidity interval	composition of particles
Mirim-jet	140 MeV/c	2-3	Mainly pions
Açu-jet	220	6-8	non-negligible
Guaçu-jet	400-500	20-30	yield of X-particles

Remark: Mirim, Açu and Guaçu mean small, large and very large in BrazilianIndian language.

After the observation of the above correlations by the UA1 Collaboration, the effect has been searched for at lower energies by other groups.

No effect was found by NA5 at $\sqrt{s}$=20 GeV[14]. The effect has also been searched at ISR by the ABCDHW Collaboration[15]. While no multiplicity dependence was detected at $\sqrt{s}$=30 GeV, a significant effect was observed at $\sqrt{s}$=63 GeV. In Figs. 15a, and 15b, we reproduce their results.

Event nicknamed Centauro I, observed in Chamber 15

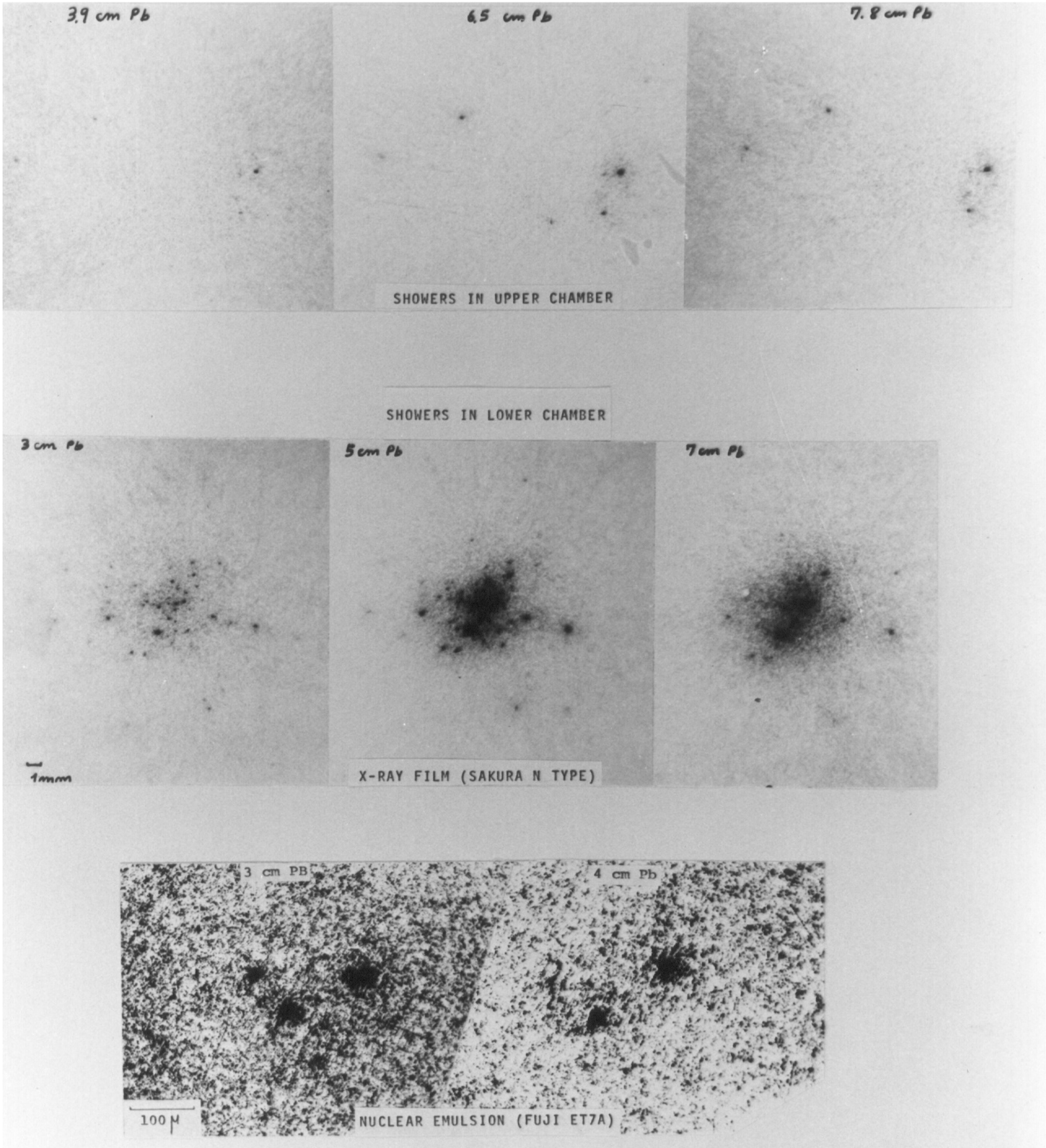
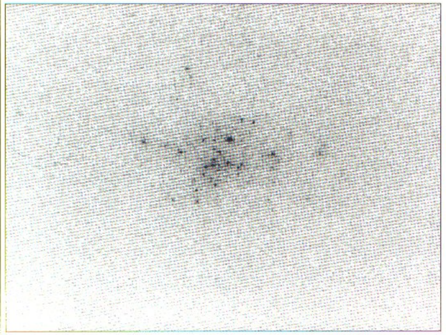
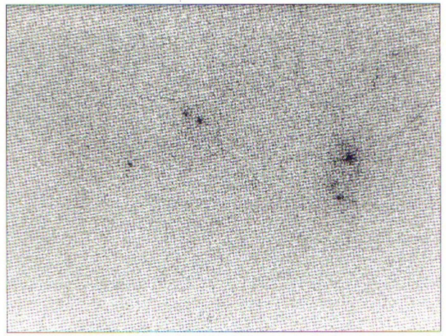


FIG. 2

February,1999
Cern Courier





One of the mysterious "Centauro" events seen by the Brazil–Japan collaboration operating X-ray emulsion chambers at an altitude of 5200 m on Mt Chacaltaya in the Bolivian Andes. Given the number of hadrons seen in the lower chamber (left) physicists are intrigued by the relative lack of corresponding electromagnetic effects in the upper chamber (right).

The mysteries of cosmic rays

Until the advent of high-energy accelerators in the 1950s, high-energy cosmic rays were the main source of information on subnuclear particles. Now they are back in the research spotlight and unexplained cosmic-ray phenomena could point to gaps in our understanding, as discussed at an international symposium.

Cosmic rays, the extraterrestrial particles which rain down on the Earth, extend to energies greater than those available via the biggest laboratory machines. This ultra-high-energy frontier is the traditional focus of the International Symposium on Very High Energy Cosmic Ray Interactions, and the most recent event at the Italian Gran Sasso laboratory highlighted the continual enigma of the universe's highest particle energies.

. High-altitude emulsion chamber experiments record the tracks left by these particles. The Pamir experiment, at an altitude of 4400 metres in Central Asia, confirmed earlier observations (April 1997, page 15) of coplanar sheets of hadrons from primary particles with energies above 8000 TeV.

This phenomenon is seen in multiple "halo" events with total visible electromagnetic energy above 700 TeV recorded in X-ray emulsion chambers. (Haloes are large black spots on the film, up to several square centimetres.) The events have several separate haloes whose centres lie in a straight line even after having passed through the atmosphere. A number of phenomenological models, some invoking unusual heavy penetrating hadrons, attempt to explain this, but the process remains a mystery.

The long-standing Brazil–Japan collaboration operating X-ray emulsion chambers at 5200 m on Mt Chacaltaya in the Bolivian Andes, described in detail a recent clean example of a "Centauro" event.

Centauros were first reported in 1980 by the Brazil–Japan team and confirmed in 1984 by the Pamir collaboration. These events contain relatively few particles, but which are almost entirely hadrons, with very few photons. They show that at these energies, hadrons can be generated without neutral pions or eta mesons (which decay into photons).

Man and horse

In Greek mythology, a Centaur was highly asymmetric, with the top half of a man and the legs of a horse. The latest physics Centauro is totally free of photons and with a similar appearance to the original Centauro I. Centauro events have always been a puzzle and remain the subject of speculation.

Other mysterious phenomena seen by these experiments include anomalous cascades penetrating very large thicknesses of densely absorbing material.

It is certainly difficult to explain the exotic phenomena seen by such high-altitude emulsion chamber experiments using conventional physics. This was underlined at the meeting by simulations described by M Tamada of Kinki, Osaka.

Março/1985

CERN collider seeks the Centaurs

Last Sunday the proton-antiproton collider at CERN generated the world's highest energy interactions yet, in a quest for some strange effects first seen in cosmic rays. The work should continue.

AT 1 a.m. last Sunday morning, jubilant experimenters at the European Organization for Nuclear Research (CERN) working on the UA5 detector on the proton–antiproton collider recorded their first events at 900 GeV in the centre-of-mass, the highest energy at which matter has been collided with matter (or anti-matter) under controlled conditions on Earth. The object over the next few weeks will be to discover if the collisions show signs of the very-high-energy "Centauro" ("centaur-like") events first detected in a Japanese–Brazilian cosmic-ray experiment in the Andes[1] as long ago as 1972, events that appear to lack all production of photons. Centauros are unexplained and treated with scepticism by most experimental particle physicists, but if they exist — and those who have studied the data carefully say they do — they would presage a fundamental reconstruction of theory.

Hence CERN's brief gamble, which, following an idea by UA5 group leader John Rushbrooke of the Cavendish Laboratory, Cambridge, involves a complicated ramping of the bending magnet current and accelerator cavities so that the colliding beams can reach — momentarily — 450 GeV apiece. The energy can only be maintained for four seconds at a time, as the magnets would overheat at the currents required to sustain the bending of 450-GeV beams. So the beams are decelerated to 100 GeV, and then brought up again to 450 GeV a few seconds later when the magnets have cooled sufficiently. It is undoubtedly an extraordinary feat of accelerator engineering, which pushes the collider energy up nearly by half from its usual constant 630 GeV maximum in the centre of mass.

The experiment certainly is a gamble, however, and CERN is treating it as such, giving UA5 the tail-end of the electricity supply year, when by contract *Electricité de France* can cut supplies to CERN for a day at a time — and usually does. There are five such *jours critiques* left before Easter, when UA5 must shut down for good. CERN staff describe experiments at such times as "crazy runs", but Rushbrooke said on Monday that he hopes UA5 will still collect some 100,000 events.

This should be enough to see if the Centauro effect is real — provided it occurs at or below 900 GeV. UA5 has already searched at 630 GeV but found no sign of the events. In the cosmic-ray experiment on Mt Chatacaya in the Andes, however, a per cent or so of the highest energy events recorded were photon-less Centauro events. (These events appeared unusually different in the upper and lower halves of the Chatalcaya detector — hence the "centaur" designation.)

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But this leaves out the question of the cosmic-ray observations themselves, and whether more can be done in that area. Undoubtedly physics smacks of the 1940s rather than the 1980s, as the events are rare and uncontrolled — as opposed to the billions of events that can be produced with tuned, intense accelerator beams. But they can be of almost unlimited energy, and still thus throw up new physics, as the Centauro events themselves indicate.

One member of the UA5 collaboration, Narendra Yamdagni of the University of Stockholm, has spent five years working with the Japanese physicists who contributed to the Centauro study, and is impressed with the evidence. This shows up not only Centauros, but also other ultra-high-energy phenomena such as "binocular" events, where the cosmic-ray collision far up in the atmosphere appears to produce two (or more) clear jets of products, and, more recently, so-called "chiron" events in which there appears to be a microscopic bunching of tracks within each jet. A Moscow collaboration working on Mt Pamir has also seen a Centauro event "even more spectacular" than the ones seen on Chatalcaya, says Yamdagni.

Yamdagni has now left cosmic-ray work to experiment on UA5 and the large electron collider (LEP) at CERN, but he strongly recommends that cosmic-ray research should be amplified, perhaps by flying 1-ton cosmic-ray experiments in routine passenger-carrying jumbo jets. "Their payload is 50–70 tons" says Yamdagni, "so it should be possible to accommodate a ton".

Cosmic-ray intensities in the stratosphere are 40 times those obtainable deeper in the atmosphere on Mt Chatalcaya, Yamdagni points out. Moreover, within a one-ton experiment, equipment (such as proportional chambers) could be included to make results less ambiguous than at present. It would also make them more acceptable to sceptical particle physicists. Japan Airlines are already flying, free, 20-cm-cube detectors designed by the Waseda University group that helped find the Centauros. Perhaps they should be 125-fold more generous, and extend the dimensions to a metre.

Robert Walgate

1. Lattes, G.M.C., Fujimoto, Y. & Hasegawa, S. *Phys. Rep.* **65**, 151 (1980).

March, 1985 - Nature

A CASTOR (Centauro And STrange Objets Research) detector is proposed to take data at LHC/CERN

CERN collider seeks the Centaurs

Last Sunday the proton-antiproton collider at CERN generated the world's highest energy interactions yet, in a quest for some strange effects first seen in cosmic rays. The work should continue.

AT 1 a.m. last Sunday morning, jubilant experimenters at the European Organization for Nuclear Research (CERN) working on the UA5 detector on the proton–antiproton collider recorded their first events at 900 GeV in the centre-of-mass, the highest energy at which matter has been collided with matter (or anti-matter) under controlled conditions on Earth. The object over the next few weeks will be to discover if the collisions show signs of the very-high-energy "Centauro" ("centaur-like") events first detected in a Japanese–Brazilian cosmic-ray experiment in the Andes[1] as long ago as 1972, events that appear to lack all production of photons. Centauros are unexplained and treated with scepticism by most experimental particle physicists, but if they exist — and those who have studied the data carefully say they do — they would presage a fundamental reconstruction of theory.

Hence CERN's brief gamble, which, following an idea by UA5 group leader John Rushbrooke of the Cavendish Laboratory, Cambridge, involves a complicated ramping of the bending magnet current and accelerator cavities so that the colliding beams can reach — momentarily — 450 GeV apiece. The energy can only be maintained for four seconds at a time, as the magnets would overheat at the currents required to sustain the bending of 450-GeV beams. So the beams are decelerated to 100 GeV, and then brought up again to 450 GeV a few seconds later when the magnets have cooled sufficiently. It is undoubtedly an extraordinary feat of accelerator engineering, which pushes the collider energy up nearly by half from its usual constant 630 GeV maximum in the centre of mass.

The experiment certainly is a gamble, however, and CERN is treating it as such, giving UA5 the tail-end of the electricity supply year, when by contract *Electricité de France* can cut supplies to CERN for a day at a time — and usually does. There are five such *jours critiques* left before Easter, when UA5 must shut down for good. CERN staff describe experiments at such times as "crazy runs", but Rushbrooke said on Monday that he hopes UA5 will still collect some 100,000 events.

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