PROCEEDINGS OF SCIENCE

HIGH ENERGY INTERACTIONS

E.H.Shibuya UFABC-Santo Andre-SP-Brazil, August 25 to September 04 2010[*†]
UNIVERSIDADE ESTADUAL DE CAMPINAS
E-mail: ehiros@hotmail.com

This text is based on a talk originally presented at the I Curso Internacional sobre Rayos Cosmicos held at LaPaz-Bolivia in January/February 1989. There, it was asked to talk on 'High Energy Interactions Through Cosmic Ray Results' and the corresponding text was never published anywhere. With small modifications the present text is almost the same as prepared previously. As this school is devoted to Cosmic Rays and Astrophysics the text describes some results obtained from Emulsion Chamber experiments, results based on a fire-ball analysis. Brief comments of main particle phenomenological models that attempts to explain Multiple Particle Production are listed. More detailed descriptions in 'Cosmic Rays and High-Energy Physics' [1], in 'Fire-Balls in Pion Multiple Production' [2] and careful discussion about models is made in [3].This text is highly recommended for interested readers.

4th School on Cosmic Rays and Astrophysics,
August 25- September 04, 2010
Sao Paulo Brazil

[*]Speaker.
[†]A footnote may follow.

PoS(CRA School)044

1. Introduction

The study of the matter is an old subject of Science. Since the Greeks, the idea of elementarity of matter, i.e. the existence of an elemental brick composing everything guided the Science, specialy Physical Sciences. Within this general objective, existence of molecules, atoms, electrons , protons and neutrons are demonstrated. At the energy in the order of MeV, one remarkable event is the particle called Meson. In 1947, this particle, proposed by H.Yukawa to explain the stability of atomic nucleus was experimentally observed in Cosmic Rays by C.M.G.Lattes, H.Muihead, G.P.S. Occhialini and C.F.Powell [4] as shown in Fig.1, and afterwards confirmed at the Berkeley accelerator by E.Gardner and C.M.G.Lattes [5]. Figs.2,3 presents disintegration of π^+ in μ^+.

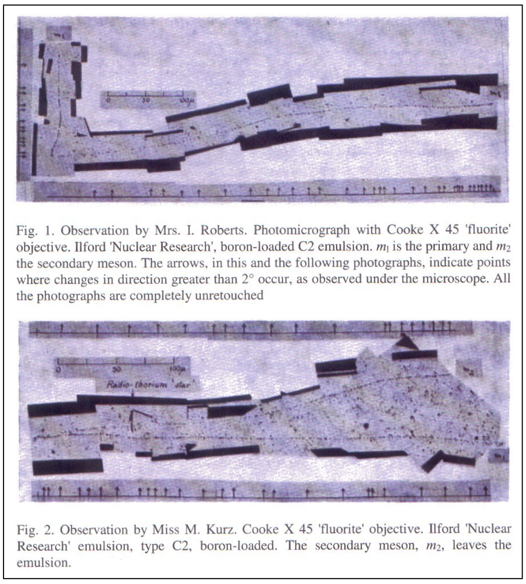

Figure 1: $\pi - \mu$ events. The upper is complete event, whereas in the lower one the μ leaves the emulsion

As a natural continuation of structure of matter studies, Cosmic Ray are largely studied up to now. Nowadays emphasys is quite different. If in the years 50, Cosmic Ray studies contributed to elementary particles discoveries, now astrophysical aspects are the main investigations through them. But, of course Hadronic Interactions studies through Cosmic Rays continued up to these days and it seems that we are looking a merge of them, today called Astro-Particle Physics.

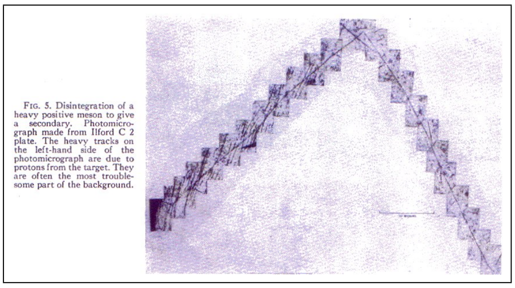

Figure 2: $\pi - \mu$ event. The π^+ was observed in Ilford C2 emulsion plate

One of beforehand mentioned Hadronic Interactions studies are carried out by the so called Brasil-Japan Collaboration on Emulsion Chamber experiments at Mount Chacaltaya, or briefly B-J Collaboration. This collaboration started effectively in 1962, after a letter of H.Yukawa sent to C.M.G.Lattes.

2. Experimental Devices

Many devices are used for Cosmic Ray induced Hadronic Interactions, like Geiger counter, ionization chamber, proportional counter, emulsion chamber, Cerenkov light detector, etc. By the way, many of these devices are invented specially for High Energy Hadronic Interactions, particularly for Cosmic Rays studies as exemplified by coincidence circuits, fast time (order of nano-seconds) apparatus, etc.

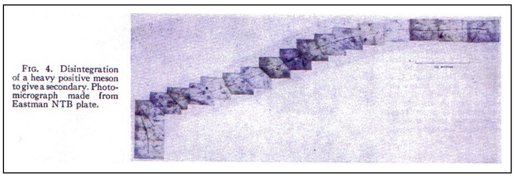

Figure 3: $\pi - \mu$ event. The π^+ was observed in Eastman NTB emulsion plate

As photosensitive plate has a good, maybe the best spatial discrimination (order of 0.1 μ m), I will describe only one device that uses it. To do this, let me start from I.C.E.F. Collaboration. This was an wordwide INTERNATIONAL CO-OPERATIVE EMULSION FLIGHT, that exposed 80 liters of emulsion and observed several hundred interactions in the exposed emulsion stacks on board of stratospheric balloons, at the Caribbean Sea during the years 1958-January, 1960. In these experiments, the nuclear emulsion works as a target and as a detector. Fig.4 shows a typical interaction producing a 'jet'. It was recognized a collimated cone of ionizing tracks and surrounding it a more spread out cone. They are called inner and outer cone, respectively. It was noted also that the radii of cones becomes smaller with increasing energy.

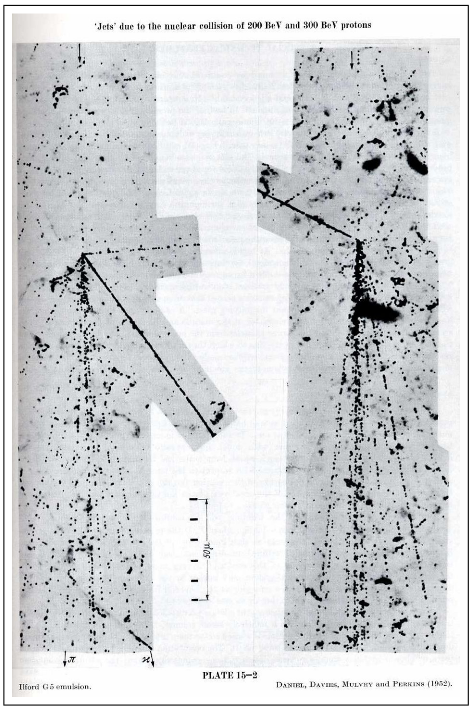

Figure 4: jets of particles

Another apparatus largely used as visual detector is Cloud Chamber. One example of the image obtained by it is illustrated in Fig.5. Note that the Cloud Chamber has some parallel lead plates inside. This material could materialize γ's through process of pair creation and bremstrahlung.

Around 1955, an apparatus called Emulsion Chamber was developed and used by Japanese researchers on Cosmic Rays. The idea comes from an experiment of Rochester group, designed to observe Cosmic Rays induced nuclear interactions in other material than the nuclear emulsion and to study mass dependence of interaction mechanism. For this purpose, they flew 2 balloons with a payload consisting of brass plates and emulsion plates placed horizontally and alternately.

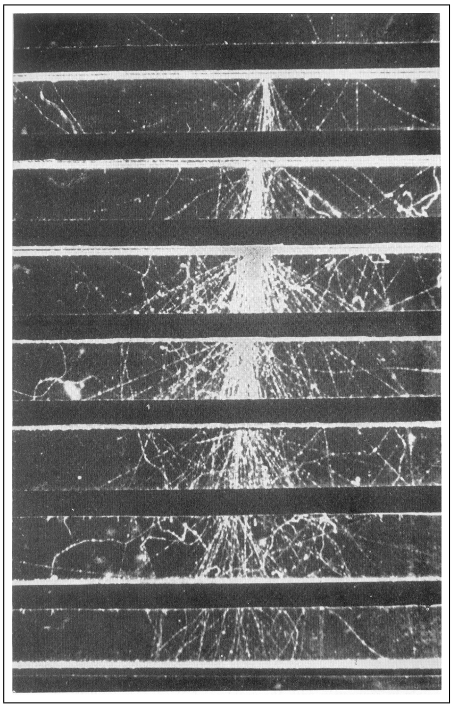

Figure 5: Cloud Chamber with lead plates

Basically, Emulsion Chamber is composed of multi-layered sandwiches of heavy density and Z(atomic number) material (Pb, Fe, etc.)and photosensitive material (X-ray films, nuclear emulsion plates). It can detect the electron shower induced by electromagnetic or by hadronic component. The energy of shower can be estimated either by spot darkness measurement on the X-ray film or by electron track counting method with use of the nuclear emulsion plates. In Fig.6 it is sketched one of such visual detector and also one typical shower development inside the detector. It is clear a similar appearance with previous Fig.5 obtained through multiplate Cloud Chamber photographs.

As mentioned before, emulsion stacks detects Hadronic Interactions in a form of cones with decreasing radii according to increase of energy. So, the energy determination through angle measurement becomes less precise for high energy interactions. To avoid this increasing indetermination it is used Emulsion Chamber for High Energy Hadronic Interactions.

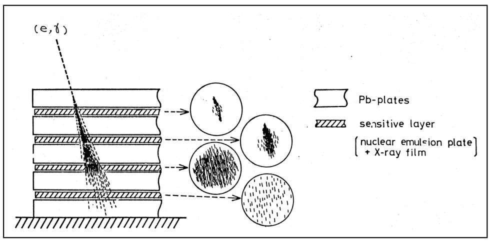

Figure 6: One unit of Emulsion Chamber

An aspect of cogenetic γ 's coming mainly from π^0 produced at the interactions is shown in Fig.7.

3. Some particle models

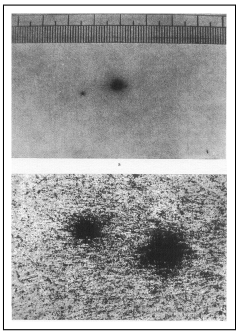

Figure 7: $\pi^0 \rightarrow 2\gamma$'s

Since 1938 an idea of multiple production of particles exists, following the work of G.Wataghin [6]. According to him, he visualized it after verifying that he couldn't explain the frequency curve of Cosmic Rays particles against atmospheric depth. Computing all particle produced through physical processes known at that time, he verified a lack of particles. Interesting to note that this idea comes out before the meson discovery.

After the discovery of 'jet', this idea was specifically used for hadrons. So, for a study of Multiple Meson Production it was introduce the concept of fireballs. The phenomena of Multiple Meson Production was stablished around 1950 after a controverse with a plural production mechanism.

G.Wataghin was one of those who proposed a cutoff method to remove ultraviolet divergences in the field theory. To give a substance to theoretical procedure, he imagined creation of an isotropic entity in the center of Hadronic Interaction with a temperature KT $\approx 3\,M_\pi c^2$, equal to meson energy with cutoff momentum. This entity, 'fire-ball' was introduced after his Cosmic-Ray experiments on meson showers.

Characteristic features on jets results are:
1)Observation of shower particles distributed in a inner and outer cones, that implies in a quite strongly forward-backward assymetry in a center of masss system.
2)Hadronic Interaction is not completely inelastic, beeing inelasticity coeficient around 0.5 on average.
3)Multiplicity increased very slowly with incident energy.
4)The fraction of energy in π -mesons decrease with incident energy, that is other particles, like Kaon is produced.

Of course, the models of Multiple Meson Particles proposed should cover these empirical features and a list of remarkable models in cronological order is:

a)Wataghin model - La Ricerce Scientifica, (1936), Symposium on Cosmic Ray, Acad.Bras. Cien. (1941-1943) and Rend.Acad.Lincei, (March 1973). This model predicts a strong multiplicity dependence, $N \propto E^{1/2}$, as a consequence of his fire-ball model.

b)L.O.W. (H.W.Lewis, J.R.Oppenheimer and S.A.Wouthuysen-October 2, 1947) model [7]. This paper 'The Multiple Production of Mesons' doesn't distinguish Pions from Muons. In fact they mention a cosmic-ray mesons (=Muons), in spite of the publication of 'Nuclear Disintegration by Meson Capture', D.H.Perkins, Nature159, (January 25, 1947),126-127, and 'Process Involving Charged Mesons', C.M.G.Lattes, H.Muirhead, G.P.S.Occhialini and C.F.Powell, Nature159, (May

24, 1947),694-699.

They considered an analogy of electromagnetic radiation of a slow electron deflected by a scatterer with a meson radiation emmited in a collision between nucleons and obtained obtained that the multiplicity of mesons rises with the cube root of the primary energy, that is $N \propto E^{1/3}$, stillm too much high dependence.

c)Heisenberg model [8]. This model predicts multiplicity dependence same as Wataghin's model, i.e. $N \propto E^{1/2}$, stronger dependence than the observed one. In this model the collision volume expands after the interaction and an analogy with turbulent motion of shock waves is used.

d)Fermi model [9]. His model is based on a interaction between the two moving meson clouds, each one having a thin disk form caused by Lorentz contraction. At the collision the whole of kinetic energy is liberated into a overlapping region of the disks. After a thermal equilibrium, the mesons are emitted from this volume obeying a statistical distribution of energy like a black-body (overlapping volume) radiation. In spite of successful predictions, this model fails to give a pronounced forward-backward assymetry and also the inelasticity is high, close to 1. The multiplicity $N \propto E^{1/4}$.

e)Landau model [10]. To permit pronounced forward-backward anisotropy, Landau modified Fermi model using hydrodynamical considerations in a way quite similar to Heisenber model but, not permitting the turbulence. As in a Fermi model, he considered the energy concentrated in a overlapping volume but the emission of mesons occurs only after expansion of this volume caused by shock waves. These shock waves appears from the collision and takes place along the line of interacting nucleons in a forward and backward direction. But other difficulties of Fermi model remains, for instance high inelasticity value. This model predicts a multiplicity $N \propto E^{1/4}$, a reasonable Kaon/Pion ratio and an important constancy of transversemomentum (Lorentz invariant quantity).

All before mentioned models belongs to a category of one emitting center, except the L.O.W. model that is not clearly of one emitting center. Another category of two or more emitting centers are:

f)Takagi model [11] and
g)Kraushaar and Marks model [12].
These models assumes that the collision leaving nucleons, in a excited state, are responsable for the emission of mesons. It predicts a relation between the value of inelasticity and the anisotropy of the angular distribution. Also predicts an inelasticity value smaller than 1, but the predicted values are still too high. A intrinsic difficult of this model is the assumption of the emission of mesons by a excited nucleons, assumption that seem not reasonable in view of collision and emission time considerations and inelasticity measurements, as described below.

h) Ciok model [13],
i) Niu model [14] and
j) Cocconi model [15]

Mainly through experimental results on angular distribution of secondaries, at least these three model of two emiting centers with nucleons flying away and followed by meson clouds are proposed. In the article of Cocconi it appears a citation **TWO FIRE BALLS**. An illustration of two fire-ball model is shown in figure, where the four-momentum Δ was estimated to be $1 \approx 2$ GeV/c after Niu analysis, i.e. $\Delta \approx M_N c$.

k) Hasegawa's H-quantum model [16]
In 1961 Hasegawa proposed this model considering an analogy of Multiple Pion Production to the emission of black-body radiation. One motivation was from a composite theory of hadrons, mainly Sakata's model, a precursor of quark-model of M.Gell-Mann [17] with the citation to S.Sakata [18]. He thought that if hadrons has a structure it should appear in the properties of fire-ball, as constant rest mass for example, avoiding a freedom to produce either a fast moving fire-ball with small rest mass, or a slow moving heavy one as permitted by two fire-ball models. Of course, an experimental motivation was considered when he observed a variety of angular distributions of events, showing many peaks not only two as in two fire-ball models. His guess for H-quantum rest energy is $M_H \approx 2\ M_N c^2$, after considering average value of multiplicity $N \approx 6$ and known value for temperature KT. This rest mass of H-quantum comes from Sakata's model, considering that the pion is constituted of a nucleon anti-nucleon pair, representing an elementary act. Under a QCD picture we may conjecture on the basis of uncertainty principle, providing that Δ characterizes size of the subhadronic composite system for a Pion. So, after nuclear interaction it is visualized formation of a tube of hadronic matter connecting the two nucleons. This tube having width $\frac{\hbar}{\Delta}$ will split into multi H-quantum with partial overlapping. After this, each H-quantum will expand till size $\frac{\hbar}{M_\pi c}$, a stage preceding transmutation into a cluster of Pions.

There are some other particle models conceived out a fire-ball concept. Some of the models therein are at the level of particles constituents like quarks, partons.

l)Feinberg's diffraction dissociation model [19]
The incident particle suffers a diffractive scattering on the target particle, whose behaviour seems an opaque disk similar to optical waves. This proccess could be either elastic and inelastic with production of secondary particles at one of both vertices.

m)Berestezky's [20], A.F.S.T.'s [21] and Hagedorn's [22] model
These models has similitudes with a multi fire-ball model like H-quantum model.

n)Yang's limiting fragmentation model [23]
A model of Benecke et al. proposes that both incident and target particles undergoes fragmentation proccess with a limite fraction of total energy. So, they could preserve a scaling behaviour as a consequence of energy independent multiplicity.

o)Gell-Mann's quark model [17]
Considering hadrons composed of 3 different objects, quarks, a model of Gell-Mann predicted occurence of unknown meson and resonances, like η-meson. Now this model had modifications with

the introduction of another quarks, charm (citar niu), top and botton quarks.

q) Feynman's parton model [24]
From inelastic high energy electron scattering results, Feynman extended a pointlike structure to the hadrons.

r) Quark-Parton-Gluon 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.

A review text 'MULTIPLE PRODUCTION OF HADRONS AT COSMIC RAY ENERGIES (EXPERIMENTAL RESULTS AND THEORETICAL CONCEPTS' of E.L.Feinberg [3] classify most of the models in 4 categories: a)Bremsstrahlung analogy and related models; b)Statistical and hydrodynamical theories; c)Hypothesis of limiting fragmentation and the parton model and d)Multiperipheral theory. In spite of some models of High Energy Interactions were constructed through analogy with Electromagnetic Interactions, others were inspired from cosmic ray experiments, for instance the reference [23] cited cosmic ray observations.

References

[1] Y.Fujimoto and S.Hayakawa, Hadbuch der Physik vol.XLVI/2-Cosmic Rays II-Springer-Verlag,115-180, (1967)

[2] Brasil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment, Prog.Theor.Phys.Supp.76,1-39,(1983)

[3] E.L.Feinberg, Phys.Rep.5C,No.5,237-350, (1972)

[4] C.M.G.Lattes, H.Muirhead, G.P.S.Occhialini and C.F.Powell, Nature159,694-7,(May24, 1947)

[5] E.Gardner and C.M.G.Lattes, Science107,270-271,(1948)

[6] G.Wataghin, Comptes Rendues des Séances de l'Académie des Sciences, v.207,358-360, (20 Juin, 1938)

[7] H.W.Lewis, J.R.Oppenheimer and S.A.Wouthuysen, Phys.Rev.73,No.2,127-140, (January 15, 1948)

[8] W.Heisenberg, Nature164,65-66,(July 9, 1949) and Z.Physik, Bd.126,S.569-582,(May 28, 1949)

[9] E.Fermi, Prog.Theor.Phys.5,No.4,570-583,(July August,1950), Phys.Rev.81,No.5,683-687,(March 1, 1951), Phys.Rev.92,No.2,452-453,(October 15, 1953) and errata at Phys.Rev.93,1434-1435,(1954)

[10] L.D.Landau, Izv.Akad.Nauk SSSR 17-Ser.Fiz,51,(1953), Suppl.Nuovo Cimento3,15-,(1956)

[11] S.Takagi, Prog.Theor.Phys.7 Lett.,123-125,(December 4, 1952)

[12] W.L.Kraushaar and L.J.Marks, Phys.Rev.93,326-330, (1954)

PoS(CRA School)044

[13] P.Ciok, T.Coghen, J.Gierula, R.Holynski, A.Jurak, M.Miesowicz, T.Saniewska, O.Stanisz and J.Pernegr, Nuovo Cimento8,No.1,166-169,(1 Aprile, 1958) and P.Ciok, T.Coghen, J.Gierula, R.Holynski, A.Jurak, M.Miesowicz, T.Saniewska and J.Pernegr, Nuovo Cimento10,No.5,741-754,(1 Dicembre, 1958)

[14] K.Niu, Nuovo Cimento10,No.6,994-1021,(16 Dicembre, 1958)

[15] G.Cocconi, Phys.Rev.93,No.5,1107-1108,(March 1, 1954) and Phys.Rev.111,No.6,1699-1706,(September 15, 1958)

[16] S.Hasegawa, Nuovo Cimento14,No.5,909-930,(1 Dicembre, 1959), Prog.Theor.Phys.26 Lett.,150-152, (April 17, 1961) and Prog.Theor.Phys.29,No.1,128-154,(January,1963)

[17] M.Gell-Mann, Phys.Rev.125,No.3,1067-1084,(February 1, 1962)

[18] S.Sakata, Prog.Theor.Phys.16,No.1,686-688,(September 3, 1956)

[19] E.L.Feinberg and I.Ya.Pomeranchuk, Suppl.Nuovo Cimento3,No.4,652-671, (1956)

[20] V.B.Berestezky and I.Ya.Pomeranchuk, Zh.Eksp.i Teor.Fiz.39,1078- , (1960)

[21] D.Amati, S.Fubini, A.Stanghellini and M.Tonin, Nuovo Cimento22,No.3,569-587, (1 Novembre 1961)

[22] R.Hagedorn, Suppl.Nuovo Cimento3,No.2,147-186,(12 Marzo, 1965),R.Hagedorn, Suppl.Nuovo Cimento6,No.2,311-354, (3 Maggio 1967), R.Hagedorn and J.Ranft, Suppl.Nuovo Cimento6,No.2,169-310, (11 Dicembre 1967), R.Hagedorn, Nuovo Cimento56A,No.4,1027-1057, (6 Febbraio 1968) and R.Hagedorn, Astron.& Astrophys.5,184-205 (1970)

[23] J.Benecke, T.T.Chou, C.N.Yang and E.Yen, Phys.Rev.188,No.3,2159-2169,(December 25, 1969)

[24] R.P.Feynman, 3rd International conference at Stony Brook, ed. Gordon and Breach, Stony Brook, New York,237- , (1969)