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POINT-COUNTERPOINT IN PHYSICS: THEORETICAL PREDICTION AND EXPERIMENTAL DISCOVERY OF ELEMENTARY PARTICLES*

by

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*Dedicated to C.M.G. Lattes on his 60th birthday.

A report is given on the theoretical prediction and the experimental discovery of elementary particles from the electron to the weak intermediate vector bosons. The work of Lattes, Occhialini and Powell which put in evidence the pions predicted by Yukawa was the starting point of the modern experimental particle physics.

Key-words: Elementary particles; Electron; Photon; Positron; Neutrino; Pion; Meson; Vector bosons.

The theoretical prediction of elementary particles and their experimental discovery have played a fundamental rôle for the development of our ideas on the structure of matter.

The experimental evidence of the electron in 1871,[1] was interwoven with theoretical work aimed at an understanding of the interaction between moving charged particles. The theoretical work of J.J. Thomson (1881), G.F. Fitzgerald (1881), O. Heaviside (1889), led to the theory of electrons, initiated and developed by H.A. Lorentz[2] in 1892, a first attempt at a description of the phenomena of production and absorption of light and radiant heat, of the electromagnetic properties of matter. This theory achieved indeed, the first unification of the domains of optics, electromagnetism (as already initiated by J.C. Maxwell), and chemistry by the assumption of certain mechanisms involving the dynamics of electrons. In the words of Lorentz, "if we want to understand the way in which electric and magnetic properties depend on the temperature, the density and the chemical constitution or the crystalline state of substances, we cannot be satisfied with simply introducing for each substance these coefficients [dielectric constant, conductivity, magnetic permeability], whose values are to be determined by experiment; we shall be obliged to have recourse to some hypothesis about the mechanism that is at the botton of the phenomena. It is by this necessity, that one has been led to the conception of *electrons*, i.e. of extremely small particles, charged with electricity, which are present in immense numbers in all ponderable bodies, and by whose distribution and motions we endeavour to explain all electric an opti cal phenomena that are not confined to the free ether"[3].

Lorentz theory contributed to the consolidation of the atomic conception of matter, a conception which although accepted by the chemists in the last century, was strongly opposed by some influential personalities such as the physical-chemist W. Ostwald and the physicist and philosopher Ernst Mach[4]. In his 1906 lectures Lorentz refers to this opposition in the following words: "Like these [the molecular and atomistic theories], it [the theory of electrons] is apt to be viewed unfavourably by some physicists who prefer to push their way into new and unexplored regions by following those great highways of science which we possess in the laws of thermodynamics, or who arrive at important and beautiful results, simply by describing the phenomena and their mutual relations by means of a system of suitable equations. No one can deny that these methods have a charm of their own, and that, in following them, we have the feeling of treading on firm ground, whereas in the molecular theories the too adventurous physicist often runs the risk fo losing his way and of being deluded by some false prospect of success. We must not forget, however, that these molecular hypothesis can boast of some results that could never have been attained by pure thermodynamics, or by means of the equations of the electromagnetic field in their most general form, results that are well known to all who have studied the kinetic theory of gases, the theories of dilute solutions, of electrolysis and of the genesis of electric currents by the motion of ions"[5].

The historical importance of the discovery of the e lectron is seen in the fact that it was the first particle to exhibit wave properties and thus allowed the development of quantum mechanics. It was for the electron that W. Pauli proposed the theoretical description of non-relativistic spin-1/2 particles by means of his two-component spinors and matrices. It was for the electron that P.A.M. Dirac invented his famous relativistic wave equation and that quantum electrodynamics and the renormalisation method were develcpped.

Already in the classical theory do we find the idea of mass renormalisation. After J.J. Thomson discovered that the magnetic field produced by a moving electron interacts with this particle and gives rise to an increase in its mass, the idea of a purely electromagnetic mass for the elctron, due to its field, was put forward mainly by M. Abraham[1]. A convenient approximation in the calculation of the electron self-field led Lorentz to give an equation of motion containing the effect of the radiation reaction on the electron namely:

$$m \frac{d^2\vec{z}}{dt^2} - \frac{e^2}{6\pi c^3}\frac{d^3\vec{z}}{dt^3} = e\vec{E}_{ext}$$

where:

$$m = m_0 + \frac{e^2}{8\pi c^2 a}$$

and a is the radius of a spherical surface over which the electron charge is distributed. The second term in the expression for m is the electromagnetic mass which diverges for a point electron[6]. If one adds it to m_0, a mechanical part of the mass, the observable mass m will appear in the equation and the important finite radiation reaction, porportional to the derivative of the acceleration is thus included in the equation. The fact that the classical self-energy diverges for a point electron was the first example of the divergences which became later the main difficulties for the quantum description of fields[7].

The first theoretical prediction of an elementary particle was that of the photon by Albert Einstein in 1905[8]. Five years earlier, the fundamental paper by Max Planck had appeared in which he introduced the assumption of discrete values, integral multiples of a minimal one, $\hbar\omega$, for the energy of the harmonic oscillators of the radiation field with frequency $\omega/2\pi$, in order to be able to derive the law of the black-body radiation.

Einstein grasped immediately the importance of Planck's work; besides his interest in obtaining a proper derivation of Planck's formula (which he achieved in 1917) his major question was, in his own words: "What general conclusions can be drawn from the radiation formula concerning the structure of radiation and even more generally, concerning the electromagnetic foundation of physics?"[8] By using Boltzmann's relation between entropy and probability, he found that the mean-value of the square of the energy fluctuation $\Delta\xi$ of a small volume of a closed system is given by the expression:

$$\langle \Delta\xi^2 \rangle = \hbar\omega E + \frac{\pi c^3}{2\omega^2}\frac{E^2}{V}$$

if use is made of Planck's radiation law, where E is the average energy, V is the volume.

The first term of the right-hand side of this equation can be interpreted if one postulates that the radiation is formed of particles - the photons - with energy $\hbar\omega$ and this term results from the fluctuations of the number of photons, similar to that of the number of molecules in an ideal gas. A similar relation was derived by Einstein for the square of the momentum fluctuations of a mirror which reflects radiation in a frequency interval ω, $\omega + d\omega$ and transmits all other frequencies and which has a Brownian motion in the radiation field. The existence of the term containing $\hbar\omega$, which could not be derived from wave theory - as the second term can-indicated that the fluctuation in a radiation field which obeys Planck's law is the sum of the fluctuations that would arise from a classical wave field and those resulting from an assembly of photons. This surprising result incited Einstein to postulate that light consists of photons with energy $h\omega$ and momentum $\hbar k$, so that all elementary processes of absorption and emission of radiation are directed processes, radiation coming in or going out in the form of needles. A report by Einstein on the constitution of radiation at the physics meeting in Salzburg in 1906, is analysed by Pauli as follows:

"It deals with both special relativity and quantum theory and contains the important conclusion that the elementary process must be directed (needle radiation) not only for absorption but also for emission of radiation, although this postulate was in open conflict with the classical idea of emission in a spherical wave, which is indispensable for the understanding of the coherence properties of radiation, as they appear in interference experiments"[9]. This conclusion was in fact "disappointing for those who still had the vain hope of deriving Planck's radiation formula by merely changing the statistical assumption rather than by a fundamental break with the classical ideas regarding the elementary microphenomena themselves"[9].

The contradiction of Planck's radiation formula with mechanics and electrodynamics was well understood by Einstein who stated in his Autobiographical Notes: "All of this was quite clear to me shortly after the appearance of Planck's fundamental work; so that, without having a substitute for classical mechanics I could nevertheless see to what kind of consequences this law of temperature-radiation leads for the photo-electric effect and for other related phenomena of the transformation of radiation-energy, as well as for the specific heat (in particular) of solid bodies"[10].

Whereas the prediction of the positron by Dirac was based on the relativistic wave equation for the electron which he invented, Einstein's prediction of the photon, based on the quantum hypothesis of Planck, was to have its full theoretical justification more than twenty years later, after the establishment of quantum electrodynamics by P. Jordan, P.A.M. Dirac and by W. Heisenberg and W. Pauli.

Dirac's invention of the relativistic wave equation for the electron was one of the most relevant achievements in theoretical physics, one in which the feeling of beauty of a theoretical construction leads its inventor to make unexpected predictions and thus grasp inner secrets of nature. This sense of beauty as a guide in the formulation of physical theories is present in several theoretical discoveries: the relativistic theory of gravitation by Einstein[11], the wave-mechanical aspect of quantum mechanics by E. Schrödinger, the work of Dirac on the positron and his beautiful speculations on possible magnetic monopoles (still not yet experimentally detected)[12].

Concerning Schrödinger's ideas on the wave equation, Dirac wrote as follows[13]:

"The big advance in the quantum theory came in 1925, with the discovery of quantum mechanics. This advance was brought about independently by two men, Heisenberg first and Schrödinger soon afterward; working from different points of view, Heisenberg worked keeping close to the experimental evidence about spectra that was being amassed at that time, and he found out how the experimental information could be fitted into a scheme that is now known as matrix mechanics. All the experimental data of spectroscopy fitted beautifully into the scheme of matrix mechanics, and this led to quite a different picture of the atomic world. Schrödinger worked from a more mathematical point of view, trying to find a beautiful theory for describing atomic events and was helped by De Broglie's ideas of waves associated with particles. He was able to extend De Broglie's ideas and to get a very beautiful equation known as Schrödinger's wave equation for describing atomic processes. Schrödinger got this equation by pure thought, looking for some beautiful generalization of

De Broglie's ideas, and not by keeping close to the experimental development of the subject in the way Heisenberg did".

"I might tell you the story", pursues Dirac, "I heard from Schrödinger of how, when he first got the idea for his equation, he immediately applied it to the behaviour of the electron in the hydrogen atom and then he got results that did not agree with experiment. The disagreement arose because at that time it was not known that the electron has a spin. That, of course, was a great disappointment to Schrödinger, and it caused him to abandon the work for some months. Then he noticed that if he applied the theory in more approximate way, not taking into account the refinements required by relativity, to this rough approximation his work was in agreement with observation". And then adds Dirac: "I think there is a moral to this story, namely that it is more important to have beauty in one's equations than to have them fit experiment. If Schrödinger had been more confident in his work, he could have published it some months earlier, and he could have published a more accurate equation".

This is also the feeling expressed by Einstein mainly after he developed the relativistic theory of gravitation. In his address delivered at a celebration of Max Planck's sixtieth birthday in 1918, before the Physical Society in Berlin wrote Einstein:

"The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction"[14]. Later on, in a lecture delivered at Oxford University in 1933, on the method of theoretical physics Einstein said:

"If, then, it is true that the axiomatic basis of theoretical physics cannot be extracted from experience but must be freely invented, can we ever hope to find the right way? Nay, more, has this right way any existence outside our illusions? Can we hope to be guided safely by experience at all when there exist theories (such as classical mechanics) which to a large extent do justice to experience without getting to to the root of the matter? I answer without hesitation that there is, in my opinion, a right way, and that we are capable of finding it. Our experience hitherto justifies us in believing that nature is the realization of the simplest conceivable mathematical ideas. I am convinced that we can discover by means of purely mathematical constructions the concepts and the laws connecting them with each other, which furnish the key to the understanding of natural phenomena. Experience may suggest the appropriate mathematical concepts, but they most certainly cannot be deduced from it. Experience remains, of course, the sole criterion of the physical utility of a mathematical construction. But the creative principle resides in mathematics. In a certain sense, therefore, I hold it true that pure thought can grasp reality, as the Ancients dreamed"[15].

The above statements by Dirac and Einstein are at variance with what was believed by scientists and philosophers after the work of Kepler, Galileo and Newton. It was then held that pure thought cannot give us any knowledge of the physical world. Physical laws would begin and end with experince. "A clear recognition of the erroneousness of this notion really only came with the general theory of relativity"[16].

Mathematical beauty and simplicity are also criteria to be found in theoretical work more closely connected with the experiment. In their 1958 paper on the theory of the Fermi interaction, Richard P. Feynman and Murray Gell-Mann established the vector-axial vector caracter of this interaction by making the requirement of a representation of fermions by two component spinors satisfying a second order differential equation and the suggestion that in β-decay these spinors enter the theory without gradient couplings. These mathematical requirements certainly assumed because "one of the authors has always had a predilection for" such equation, were the guiding lines for the determination of the Lorentz nature of the weak coupling. And the fact that this coupling was in disagreement with experimental results concerning the electron-neutrino angular correlation in the He^6 decay, did not discourage the authors from publishing their paper. On the contrary, their feeling of mathematical beauty and simplicity led them to write: "These theoretical arguments seem to the authors to be strong enough to suggest that the disagreement with the He^6 recoil experiments and with some other less accurate experiments indicates that these experiments are wrong"[17]. They were found out to be indeed wrong and the predictions by Feynman and Gell-Mann and independently by Marshak and Sudarshan[18] were confirmed experimentally.

The theoretical prediction of the positron was based, as is well known, on an ingenuous redefinition of the vacuum so that the negative energy solutions of the electron Dirac's equation-which cannot be discorded since they form, with the positive energy solutions, a base in the spinor space could be physically acceptable. Here is Dirac's testimony on this formulation: "The physicist had always previously thought of the vacuum as a region where there is nothing at all, but that was a prejudice which we have to overcome. A better definition of a vacuum would be the state of lowest energy. Now if there are possibilities of electrons having negative energies, we should want to have as many of these electrons as possible in order to get the lowest energy. Electrons obey the Fermi statistics corresponding to antisymmetrical wave functions. They satisfy Pauli's exclusion principle which means that not more than one electron can be in any state"[19] This picture led "to the possibility of our understanding states which depart from the vacuum in two ways, either by having electrons in positive energy states or by having holes among the negative energy states. And the holes among the negative energy states appeared as particles with a positive energy and charge, which were later interpreted as positrons"[19].

There was, however, in the 1920's and up till the end of the 1940's a prejudice against assuming the existence of new particles. This was quite understandable as it was then thought that electrons, protons and photons would be sufficient to describe matter and energy-in accord perhaps with the quasi-unitary ideal of the atomistic conception of matter. Dirac was thus incited to identify a hole in the sea of negative energy electron states with a proton, which was not correct since the antiparticle (hole) must have the same mass as the corresponding particle-as pointed out first by J.R. Oppenheimer.

Dirac's conception of the vacuum thus led to the prediction of a new particle-the positron, discovered experimentally in 1932 by C.D. Anderson and by P.M.S. Blackett and G.P.S. Occhialini[20]. And it was fortunate that Dirac did not get discouraged by the fact that his definition of the vacuum gave rise to divergences associated with the infinite sea of holes.

The discovery of the antiproton and the antineutron many years later[21] confirmed the conception that Dirac's equation describes every spin 1/2 particle which then has an antiparticle associated to it.

As to the neutrino-presently, the neutrino associated with the electron-its theoretical prediction was made by Pauli as early as 1930, in a letter to a group of physicists who had a scientific meeting in Tübingen. At that time, electrons detected in the beta decay of radioactive nuclei were shown to have a continuous spectrum of energy instead of a unique energy given by the difference between the masses of the initial and final nuclei/plus recoil energy), the maximum of the spectrum. In opposition to a radical suggestion by Niels Bohr that the law of conservation of energy would be violated in these processes, Pauli proposed that a neutral light particle-which be called neutron-is emitted together with the electron and the energy available is thus distributed between them. In his own words:

"Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquantun ausserdem noch dadurch unterscheiden dass sie nicht mit Lichtgeschwindkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronen Masse sein und jedenfalls nicht grösser als 0,01 Protonenmasse. Das kontinuierliche β-spectrum wäre dann verständlich unter der Annahme, dass beim β-zerfall mit dem Elektronen jeweils noch ein Neutron emittiernt wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist"[22].

Pauli's proposal was taken up by E. Fermi who formulated, in a beautiful paper[23], his theory of beta-decay, which was to be the basis of the subsequent development of the physics of weak interactions.

The neutron-a neutral particle with mass of the order of that of the proton-was experimentally discovered by J. Chadwick in 1932, after speculations in 1920 by E. Rutherford[24] who conceived "the possible existence of an electrically neutral particle, which he visualized as a close combination of a positively charged proton and a negatively charged electron so that the whole particle would have no electrical charge"[25].

Clearly, Chadwick, who worked at the Cavendish Laboratory under Rutherford, was destined to discover the neutron as he began to look for it[25] since the year 1924. In 1931, H. Becker and W. Bothe found that beryllium, when bombarded by alpha particles emitted penetrating neutral particles which they thought were gamma rays. The experiment was repeated by F. Joliot and Irene Curie[26] who discovered that these particles, if they hitted a paraffin target, gave rise to very fast moving protons. This discovery led immediately Chadwick[26] to suspect that the penetrating particles emitted in the alpha particle-be ryllium reaction were Rutherford's neutron and his observations confirmed this. After the discovery of the neutron, D. Iwanenko[27] suggested that nuclei are formed of protons and neutrons. This idea was adopted by Fermi in his paper on the beta-decay theory[23], and in his Seminars in Rome he called Pauli's particle a neutrino to distinguish it from the neutron; he also postulated that electrons and neutrinos do not exist in nuclei, they are rather created and emitted in the decay process just like photons in the radiation emission process.

Mesons were theoretically predicted after the discovery of the neutron and the Pauli suggestion of the neutrino. In 1935, Hideki Yukawa assumed that the nucleon interactions were due to the creation of a field by this particle--a neutron or a proton-and that the virtual exchange of quanta of this field between nucleons would give rise to the nuclear forces. Moreover, by relating the range of these forces with the mass of these quanta-the mesons-he found this mass to be of the order of 200 electron masses. In spite of the beauty of the idea which be introduced, Yukawa became discouraged with this value of the mass. He said: "As such a quantum with large mass has never been found by experiment, the above theory seems to be on a wrong line"[27].

It was only in 1947, after fundamental scientific research was taken up again following the end of the Second World War that Yukawa's particle was found experimentally. In a series of beautiful experiments with nuclear emulsions exposed at an altitude of more than 4000 meters, at the Chacaltaya Laboratory of Cosmic Physics in Bolivia, C.M.G. Lates, G.P.S. Occhialini and C.F. Powell[28] discovered the π-mesons (pions), the charged and neutral quanta of Yukawa's field. Moreover, they showed that another particle, slightly ligther than the pions, existed, the muons, which exhibited no strong interactions and which were produced in a decay of pions, together with a light particle, the muon-neutrino as it is known today.

At about the same time observations were made by M. Conversi, E. Pancini and O. Piccioni[29] which suggested the existence in the cosmic radiation of weakly interacting particles. Whereas the pions were shown to have spin zero, the Conversi-Pancini-Piccioni particles were shown to be the muons of Lattes, Occhialini and Powell and to have spin 1/2. These discoveries were important as they opened the door to the modern elementary particle physics. I had the occasion to follow closely these developments as Lattes and I exchanged[30] correspondence on his experimental work (see letter at the end of this paper) and spent some time together when in 1949 he visited me at the Institute for Advanced Study, where stayed H. Yukawa, W. Pauli, J.R. Oppenheimer, Oskar Klein, A. Pais, J. Steinberger and Chr. Møller as well as with W. Schützer and J. Tiomno, working at that time at Princeton University. The attribution of spin 1/2 to muons was basic in a paper by J. Tiomno and J. A. Wheeler[31] in 1949, in which the idea of universality of weak interactions was proposed. Those were for me personally exciting years as at that time I was also trying to establish conditions at the Federal University in Rio de Janeiro so that Lattes and Tiomno could come to our Physics Department. This was made possible-a group active in research in nuclear and par-

particle physics-by the creation of the CBPF-the Brazilian Center for Research in Physics in 1949 in Rio de Janeiro, an initiative which would not have been possible had we not received full support from João Alberto Lins de Barros, a very intelligent man, active in Brazilian politics, and his brothers, Henry British and Nelson. This Center and the Physics Department of the University of São Paulo were the two institutions which gave the initial momentum to the development of modern theoretical and experimental physics in Brazil[32].

I shall not discuss now the subsequent discoveries of new particles: the strange particles and the ressonances, the theoretical prediction of quarks and the quark model, the consideration of intermediate vector bosons, the lepton tau among others. I shall, however, take this opportunity to describe here the motivations which led me to assume, in 1958, the existence of neutral vector bosons, besides the charged ones, and to propose that the coupling constant g of the weak vector boson field with matter should be equal to the elementary electric charge e, the coupling constant of the interaction between photons and matter[33].

When the paper of Feynman and Gell-Mann on the V-A weak interaction was published in 1958 I had just returned from the California Institute of Technology where I had completed work[34] on the capture of negative muons by light nuclei in which the first calculation of the induced pseudoscalar coupling was made. As I read the Feynman-Gell-Mann paper I was immediately struck by the fact that, if these interactions were mediated by vector bosons, as already suggested in that paper, they were perhaps deeply related to photons which were also vector particles. I had the feeling that somehow photons and weak vector bosons belonged to the same family and that therefore the coupling constant g should be equal to the charge e. As this assumptiom was introduced in the well-known relation between g, the Fermi constant G_F and the bosons mass m_W, I found that m_W was quite large, of the order of 60 proton masses. But then I felt discouraged: how could I put in a multiplet particles with such a mass difference, the massless photon and these heavy bosons? As the mechanism of mass generation was unknown at that time I avoided stating in my article that photons and vector bosons were members of a multiplet (the fear of the referees...). But I did say that the assumption g = e implied a very heavy vector boson. On the other hand, I knew that in the meson theory of nuclear forces, charged and neutral pion fields enter the lagrangean in a form which gives a charge independent interaction. The interactions between the pion and the nucleon fields is independent of whether the nucleons are electrically charged or not and is invariant under the SU(2) group. I wanted to see whether this would happen for weak interactions. I therefore assumed the existence of neutral vector bosons-now called Z_0- and found that the coupling would not be charge independent: neutral currents would have a coupling with Z_0, different in form from that between charged currents and the W field.

In 1958 neutrino beams were not dreamt of and only one neutrino was assumed to exist. As a test for the neutral current interaction I then proposed investigation on a possible weak coupling between electrons and neutrons-possibly added to the magnetic moment interaction. If such a coupling were found it could only be due to an exchange of neutral bosons.

This intuitive model was later found out to be essentially correct as a consequence of the beautiful work of S. Weinberg, A. Salam and S. Glashow, who established the electroweak dynamics.

The neutral boson and the charged boson were discovered experimentally[36] in 1983 and their mass, as derived in the above mentioned gauge theory, is of the order of the value I had guessed; the relation between g and e, instead of a simple equality is of the form

$$e = g \sin \theta_W$$

where

$$\sin \theta_W = \frac{g'}{(g^2+g'^2)^{1/2}}$$

$$\cos \theta_W = \frac{g}{(g^2+g'^2)^{1/2}}$$

g and g' are the two constants in the $SU(2) \otimes U(1)$ standard model from which e and $\sin \theta_W$ are deduced.

The beautiful experiments of the UA1 Collaboration at CERN confirm the new vistas in fundamental physics afforded by the gauge field theories as Lattes, Occhialini and Powell at the end of the 1940's opened the path to the discovery of new elementary paricles.

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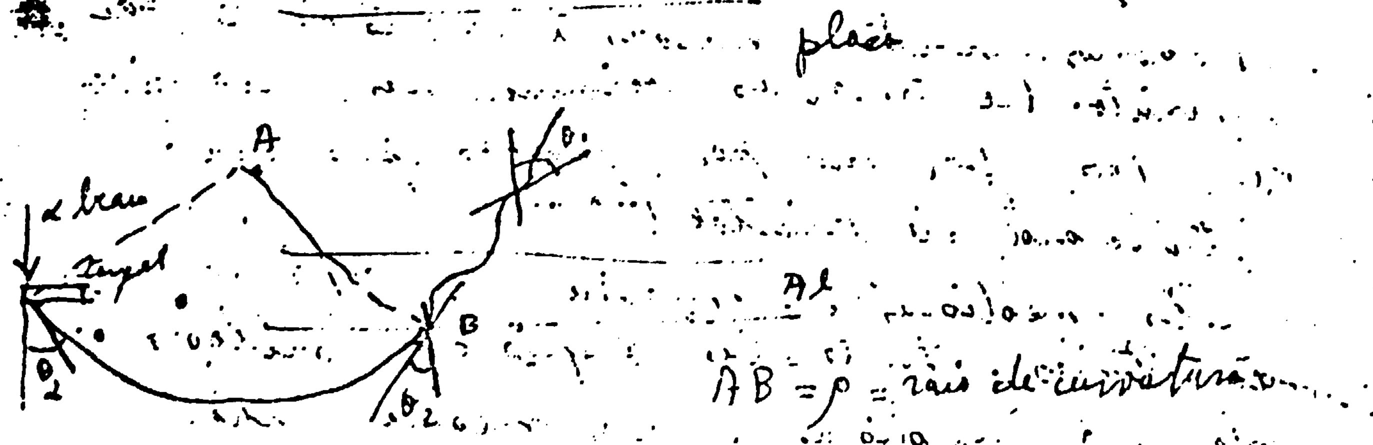
AIR MAIL — Caro Leite.— 6

Estive esperando que o trabalho sobre o meson fosse desclassificado pela comissão de energia atômica para poder enviar os resultados sem provocar encrencas.
Junto lhe copia do trabalho que sairá em "Science", o equivalente de Nature aqui, na próxima semana. Infelizmente não tenho fotografias à disposição por falta de tempo mas os mesons são tais e quais aos de Bristol.
Logo que o pessoal se acalmou um pouco (já tive que fazer 4 seminários!) consegui trabalhar um pouco. Temos agora condições muito melhores. Conseguimos reduzir o background de fast neutrons e agora temos 10 protons background para 1 meson! Em algumas placas o número de mesons que entra na placa pela aresta é 90% dos traços!
Podemos encontrar mesons à razão de 5 por minuto (e tomar as coordenadas) ao invés de 100 por ano por pessoa que era o standard de Bristol!
As medidas de massa por r/p e range são ótimas. Junto lhe gráfico do resultado de 50 medidas. A média não pesada (traços mais curtos tem peso estatístico menor) é 313 ± 16. O erro é quase só sistemático, devido ao fato que

nestas experiências preliminares não fixamos bem a posição da placa. O erro sistemático poderá ser diminuído a cerca 1% quando fizermos a exposição com mais cuidado.

O "spread" dos valores das massas já é melhor do que qualquer medida feita em camara de Wilson para mesons cósmicos mas será grandemente reduzido no futuro. Nas medidas atuais tínhamos uma janela de Al de 24.5μ e medíamos a direção do traço para determinar o ângulo θ_c dentro na emulsão, pois no "edge" há deformação da gelatina. Ora nossos mesons, nas condições de nossa exposição, tem energia pequena (~3 MeV) de maneira que o scattering é grande e o ângulo θ_c será $\neq$ de θ_2 que é o que precisamos para determinar o raio de curvatura.



AIR MAIL

- Em experiências futuras usaremos folha de 1/1 de 1, e forçamos os mesons entrar na placa "at glancing angle through the surface of the emulsion".

Acho que chegaremos a obter a massa dos mesons com precisão de 1 a 2% pois o método é ótimo.

Não fizemos ainda grain counting.

By the way, em Bristol tínhamos

$$\frac{m_\pi}{m_\mu} = 1.65 \pm 0.11 \quad \text{by grain counting}$$

$$\frac{m_\pi}{m_\mu} = 1.50 \pm 0.20 \quad \text{by small angle scattering}$$

média pesada $\frac{4 \times 1.65 + 1.50}{5} = 1.62 \pm 0.10$

Se $m_\mu = 200$, $m_\pi = 324 \pm 20$

Pretty good isn't it?

Tomando $m_\pi = 313$ e $m_\mu = 200$

Temos, para o meson decay:

$$\begin{cases} 313 = E_\mu + E_0 \\ m_\mu^2 - m_0^2 = E_\mu^2 - E_0^2 \end{cases}$$ energia relativista, $c = 1$

$$\frac{m_\mu^2 - m_0^2}{313} = E_\mu - E_0$$ m massa de repouso

$$2E_\mu = \frac{m_\mu^2 - m_0^2}{313} + 313$$

Mas $E_\mu^{\text{cinética}} = 4$ Mev $= 8$ e.m.

Logo $E_\mu^{\text{total}} = 208$ e.m.

$$\therefore \frac{m_\mu^2 - m_0^2}{313} = 416 - 313$$

$$m_\mu^2 - m_0^2 = 103 \times 313 = 32239$$

$$\therefore m_0^2 = 40000 - 32239 = 07761$$

$$m_0 \cong 88 \text{ e.m.}$$

Tive que fazer o calculo aqui pois não tinha feito.

A massa acima depende de $m_\mu = 200$ que não é conhecida com muita precisão.

É possível que o cyclotron esteja fabricando mesons neutros em grandes quantidades.

Vamos procurar detectá-los "by showering" the electron; e procurando estrelas do tipo

$$O_8^{16} + \gamma_0 \to 4\alpha$$

$$C_6^{12} + \gamma_0 \to 3\alpha$$

Talvez a vida media seja muito curta para isso.

Ainda não temos medidas de precisão sobre o espectro de energia mas é provavel que chegue até cerca 50 Mev.

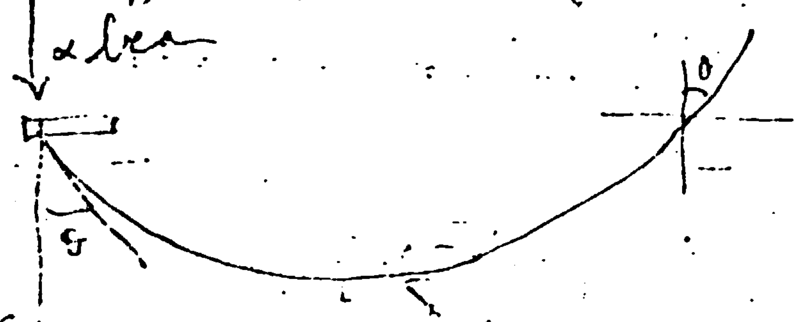
Conseguimos mesons bombardeando C_6^{12} com α de 90% x 380 Mev e 300 Mev

AIR MAIL

Mas em quantidade muito menor. Ainda não temos medidas de "excitation curve".

Estude os artigos citados no trabalho.

A distribuição angular está sendo feita. É facílimo obtê-la pois o angulo com que os mesons entram na placa é igual ao com que sae do target:



Não temos dados suficientes mas chega até 45° pelo menos.

Serber está calculando a cross section $\sigma = f(E_\alpha) \to \sigma f(E_\alpha, \theta)$ pelo modelo Mc. Millan - Teller.

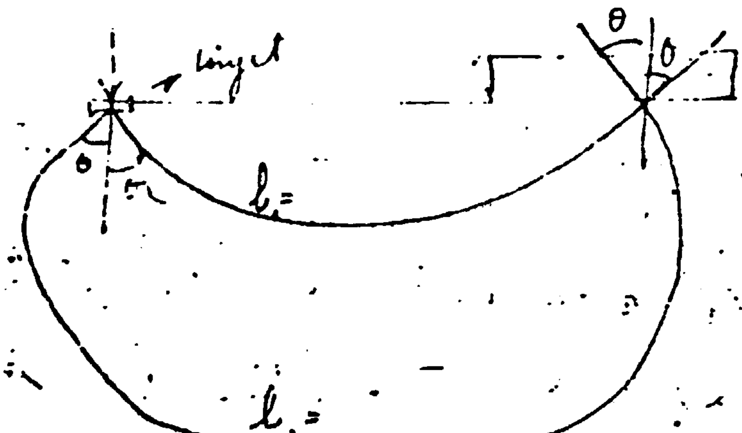
Não temos medidas precisas de $\sigma = f(Z)$ Z = nº atomico do target. Tentamos Be, Cu, (não confundir) U com resultados da mesma ordem de grandeza que C. Be talvez mais mesons que C. Naturalmente tentaremos todos os targets.

A vida média deve ser

$$\tau \geq \left\{ \sim \frac{\pi \times 8}{3 \times 10^{10}} \right\} \sim 10^{-9}$$

que é o caminho percorrido (dentro do) no campo magnético.

Uma medida muito exata de τ pode ser feita comparando o número de mésons que entra na placa segundo ângulo θ com o de $-\theta$:



pois p e portanto E é o mesmo. Só será necessário fazer correções para o ângulo sólido.

Faça o cálculo e verá que o nº que decai não depende de p pois se p aumenta v aumenta proporcionalmente.

Não é bonito?

Quanto ao que acontece no fim do traço dêsses mésons negativos 100% e pesados 100%:

Em 50 casos examinados com cuidado:

34 dão estrelas de 1 próton ou mais
12 não dão
4 não é possível saber.

AIR MAIL

Como em alguns (muito) ... casos o meson dá só um proton

de grande energia (dificil de ver-se) é claro que se o proton sai muito inclinado em relação ao plano da emulsão, será dificil de ver. Além disso em alguns casos teremos somente neutrons emitidos.

Além disso metade da emulsão em volume é gelatina. Como os grãos de AgBr teem dimensões $\simeq 0.1$ micron é provavel que o meson tenha 50% de probab. de parar em AgBr e 50% na gelatina. Na gelatina 20% são atomos de H_1. Serber está calculando a prob. de captura por H em relação a C, N, O, Ag e Br que são os demais constituintes da emulsão. Resultados preliminares (citados no artigo de Fermi e (Al.) dão prob. pequena para H, mas em todo o caso, a reação seria

$$H_1 + \mu \to N_1 + \gamma$$

não daria nada ao fim do range.

Isso tudo leva a concluir que provavelmente todos os mesons pesados (−) são capturados, como deveria ser (Fermi etc)

Quanto aos leves, ainda não procuramos ver se são produzidos diretamente [illegible] bombardeio pelo α. É provável que não incidentemente (por ter weak interaction) em todo o caso vamos procurar ver o que acontece quando reduzimos a energia dos íons. Com a energia que usamos eles saíam muito rápidos para deixarem traços na emulsão.

Outra coisa a favor de que os $\pi^{(-)}$ são sempre capturados é o fato de não termos observado decays.

Os nossos resultados parecem indicar que os μ^{-}-vos nunca produzem estrelas pois em Bristol tínhamos 900 mesons π 100 π^{+}-vos e 100 mesons dando estrelas. Se os μ^{-} dessem estrelas ao serem capturados por Ag ou Br (50% dos casos) deveríamos ter

$$\frac{34}{46} \times 100 = 75 \text{ estrelas devidas a } \pi$$

e

$$\frac{(900-300)}{2} \times \frac{1}{2} = 150 \text{ estrelas devidas a } \mu$$

Total 225

x———x

By the way, logo que conhecermos T_π podemos calcular $H\rho$ de maneira a ter determinação exata [illegible] [illegible] do contato

O Alvarez propoz o seguinte que acho ótimo:

Os "muttrons" foram descobertos nos raios cósmicos e assim chamados por Anderson. Ficaria para mudar o nome depois de 10 anos.

Os mésons são responsáveis pelas forças mesonicas. Ficaria para mudar o nome depois de tanta "teoria mesonica".

Hoje, porque não chamar mesotrons os leves e mesons os pesados? Ou tal.

Desculpe a desordem de idéias na carta pois fui escrevendo como me vinha pela cabeça.

Vou a Washington D.C em Abril apresentar o trabalho sobre mesons artificiais no meeting da A.P.S. (despezas pagas pela C.E.A...). Recebi convite para invited paper no Symposium e Colloquium do Caltec em Junho (despezas pagas pelo Office of Naval Research) e meeting da A.P.S. Como vê o credito começa a vir...

Um abraço

Cesar