Evidence for the generation of baryons from electromagnetic instabilities of the vacuum from a comparison with energetic cosmic rays data for protons.

Osvaldo F. Schilling

Departamento de Física, Universidade Federal de Santa Catarina, Campus, Trindade, 88040-900, Florianópolis, SC. Brazil

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Abstract:
Following previous work, we present a field-theoretical treatment in which baryons are generated from perturbations of magnetodynamic origin built upon a background sea of excitations located by the model at 3.7 GeV. A Zeta-function regularization procedure previously adopted for the Casimir Effect is applied to account for the infinite range of the excitations spectrum, and states of negative energy compared to the background state(in the physical form of vortices) are obtained to represent the baryons. A prediction of this theory is that if the energy difference of 2.7 GeV between the vacuum background energy level and a proton rest energy is surpassed by energetic protons, such particles might not be detected since the vortices would become unstable. In reality, a marked *decrease* in the flux of cosmic rays protons is observed beyond 2.7GeV kinetic energies. Such results gives support to the existence of a vacuum energy state at 3.7 GeV, but the fact that protons are still observed in small amounts even at extremely high energies cannot fit in the simple vortex picture. We argue that at very high energies the binding interactions between individual constituents inside protons not considered in the vortex picture become relevant and this determines the survival of part of the protons in the rays.

1. Introduction.

The present paper contains the main results of investigations on the scope of applicability of quantum electrodynamic concepts in the realm of particle physics. Extensive use of ideas previously advanced by Barut, Post, Jehle , among others, has been made, some of them rediscovered independently by the author. For the sake of brevity we are not going to reproduce details already contained in previous publications [1,2]. For short, the main idea in this treatment (following mainly Herbert Jehle) is that the existence of a magnetic moment is crucial for the existence of baryons. The presence of such moment is *modelled* by the introduction of an intrinsic closed electrical current loop(zitterbewegung), and the resulting confinement of magnetic flux is in principle assumed as occurring in integer numbers of flux quanta. The treatment here is simple enough not to introduce considerations of Jehle and others on the topology of these hypothetical currents distributions. In paper [1] we have shown the following. It has been possible to describe the masses of all the baryons of the octet and decuplet in terms of a unique formula involving the magnetic moments and corresponding numbers of confined flux quanta. This initial treatment was essentially heuristic, but powerful enough for instance to highlight the dependence of mass upon the square-root of the spin, as reported elsewhere in the literature. The results of this initial publication made clear that mass is a property essentially determined by electrodynamic energies, not requiring further inputs from other kinds of interactions at shorter scales. In paper [2], whose main results are reproduced in the following sections, we went much further. We started by taking the practical step of defining the number of confined flux quanta in terms of the measured masses and moments of the particles. By doing that we immediately recovered a particular result which has been reported mainly through condensed matter physics investigations, that is, the periodic behavior of energy of currents with confined magnetic flux in multiply connected structures. The periodic behavior of baryons masses with the magnetic moments (and confined flux) can be regarded as a fingerprint demonstrating that the initial hypotheses of the present investigations were sound. That is, indeed mass is a manifestation of magnetodynamic energies (related to currents) confined in a multiply connected region. Such hypothesis is therefore consistent with experimental data. With this evidence in hand the next step clearly was the need to go beyond the initial phenomenological-heuristic argumentation and propose a field-theoretical treatment that would describe the observed mass –energy relations for closed currents. Such kind of treatment has already been applied for fermion fields around a closed loop containg magnetic flux. Starting from a Lagrangian suitable to these fermion fields(a proton field, following Barut), we then obtained an energy spectrum for the possible current-carrying states around a closed path. In order to simulate perturbations related to interaction with the vacuum background, a sum over the states in the energy spectrum of kinetic energies for the fermion is necessary. An Epstein-Riemann zeta-function regularization procedure previously adopted for the Casimir Effect is applied to eliminate divergences when the sum upon the energy spectrum states is carried out, and the periodic behavior of the baryons masses with magnetic flux is reproduced with no further forms of energies required besides the magnetodynamic terms. This is the point where we begin the present work. Formulas and results from [2] are presented again for the sake of completeness.

A new result of this treatment, already divulged in [2], is the prediction of a parent state at $U_0 = 3.7$ GeV , which should be identified with the vacuum sea of excitations in equilibrium which would give origin to baryons. The present work goes beyond [2] in the search for evidence for the existence of this state. The calculated value of U_0 immediately indicates that protons (of rest mass of about 1 GeV) should become unstable if accelerated to kinetic energies beyond 2.7 GeV. We do find evidence for that in the lower range of energies of protons in cosmic rays. The reported flux of protons indeed falls markedly for kinetic energies beyond 2.7 GeV, although it remains finite up to the extreme relativistic limits rather than completely disappearing . This remarkable finding leads to two (ironically) related concusions. The first one is that it confirms that the field-theoretical model works, and the proposed parent state actually exists at the predicted position. The second conclusion is that the vortex model has a limited range of application, though, and the proof is that the flux of protons does not disappear, but still exists at very high energies. The reason however is clear: the vortex model neglects any internal structure for the proton, which is obviously an oversimplification. The finite cosmic rays flux at high energies indicates that interactions at length ranges shorter than the size L/π of the vortex (see below) are strong enough to (statistically) keep the proton constituents together. The simplified vortex model predicts an abrupt fall of the flux of protons at 2.7 GeV kinetic energy, while the observed drop forms a long tail.

In the following sections we firstly recall the field-theoretic model introduced in [2], alongside the comparison with experimental data for mass and magnetic moments for baryons. In the Analysis section we test the hypothesis of the existence of an energy background level for vacuum by examining data collected for protons in cosmic rays. We then present the Conclusions.

2. Theory

2.a. Vortex model for baryons, based upon Field-Theoretic concepts [2].

For the developments that led to this field-theoretic treatment we make reference to the Annales paper[1](see also references therein and in ref.[2]). Let´s consider a fermion field confined to a circular path of length L, enclosing an amount of self induced magnetic flux ϕ, in a potential $\boldsymbol{A}$. We need to show that such a system corresponds to a state detached from a higher state associated with a sea of excitations in equilibrium, and therefore might be used to represent a "quasiparticle". The relativistic Lagrangian for such a fermion can be modelled through the dressing of a proton of mass m_p in view of the presence of magnetodynamic terms[2]:

$$\mathcal{L} = \bar{\psi} \left\{ i\alpha_\mu \left(\hbar \partial_\mu - i\frac{e}{c} A_\mu \right) - \alpha_4 m_p c \right\} \psi \qquad (5)$$

Where the α_i are Dirac matrices. This Lagrangian can readily be transformed into a Hamiltonian form. For A a constant around the ring path, the spectrum of possible energies for a confined fermion are obtained as:

$$\varepsilon_k = c\{(p_k - eA/c)^2 + m_p^2 c^2\}^{1/2} \qquad (6)$$

which comes straight from the orthonormalized definition of the Dirac matrices and diagonalization of the Hamiltonian. If one takes the Bohr-Sommerfeld quatization conditons the momentum p_k (for integer k) is quantized in discrete values $2\pi\hbar k/L$. We start from this assumption but the true boundary conditions to close the wave loop might impose corrections to this rule in the form of a phase factor(see below). The potential A can be replaced by ϕ/L . Such charge motion is affected by vacuum polarization and the effects on the kinetic energy are accounted for in a way similar to that used in the analysis of the Casimir Effect, by summing over all possible integer values of k in eq.(6) [2]. This summation diverges. According to the theory of functions of a complex variable the removal of such divergences requires that the analytic continuation of the terms be taken, which reveals the diverging parts which are thus considered as contributions from the infinite vacuum reservoir. A successful technique for this purpose begins with the rewriting of eq.(6) in terms of Epstein-Riemann Zeta functions[2], including the summation over k from minus to plus infinity integers, and making a regularization (Reg) transformation. Here M (ϕ) is the flux-dependent dressed mass of a baryon, and s $\rightarrow -1$:

$$M c^2 = U_0 + \mathrm{Reg} \sum_k c\{(p_\mathrm{k} - e\phi/Lc)^2 + m_\mathrm{p}{}^2 c^2\}^{-\mathrm{S}/2} \qquad (7)$$

where we have allowed for the existence of a finite energy U_0 to represent an hypothetical state from which the individual baryons would condense, since they would correspond to lower energy states. Such particles should be characterized as states of energy Mc^2 lower than U_0. It is convenient to define from L a paramer with units of mass $m_0 = 2\pi\hbar/cL$, which will be used to define a scale in the fit to the data. We notice that m_0 is related to the parameter L in the same way field-theories regard mass as created from broken symmetries of fields, establishing a range for an otherwise boundless field distribution(e.g., as happens at the establishment of a superconductor state with the London wavelength related to an electromagnetic field "mass" by a similar expression). For convenience, we define the ratios $m' = m_p / m_0$ and $u_0 = U_0 / m_p c^2$. For comparison with the data analysis in our previous work[1], we must introduce also the number of flux quanta n (integer or not) associated to ϕ, such that $n = \phi/\phi_0$. In terms of these parameters one may write (7) in the form:

$$M(n)/m_p = u_0 + (1/m')\mathrm{Reg} \sum_k \{(k-n)^2 + m'^2\}^{-s/2} \qquad (8)$$

In the analysis of data the experimental values of M/m_p for baryons will be plotted against n. The sum in the right side of (8) is a particular case of an Epstein Zeta function $Z(s)$, and becomes a Riemann Zeta function, since the summation is over one parameter k only. The summation diverges but it can be analytically continued over the complex plane, since the Epstein Zeta function displays the so-called reflection property. It has been shown that after the application of reflection the resulting sum is already regularized, with the divergencies eliminated. The reflection formula is[2]:

$$\pi^{-\frac{s}{2}} \Gamma\left(\frac{s}{2}\right) Z(s) = \pi^{\frac{s-1}{2}} \Gamma\left(\frac{1-s}{2}\right) Z(1-s) \qquad (9)$$

This replaces the diverging $Z(s)$ straight away by the regularized $Z(1-s)$, which converges(since $\Gamma(-1/2) = -2\sqrt{\pi}$ we see that the regularized sums are negative, like in the Casimir Effect solution).
For the sake of clarity we describe now the regularization of eq.(8) below as eq.(10), step by step (note that $s \to -1$, and the "reflected" exponent $-(1 - s)/2$ replaces $-s/2$ of (8)).
In the first passage from the left the entire summation argument is replaced by the Mellin integral which results into it. This creates a convenient exponential function to be integrated later. In the second passage the Poisson summation formula is used, in which the summed

exponential function is replaced by its Fourier Transform (note that the same notation k is used for the index to be summed in the Fourier Transformed quantity). The objective is to replace the k^2t in the initial exponential by k^2/t. In this way, when the integration over t is carried out a modified Bessel function K is obtained. In the final line the k=0 term in the sum is separately worked out and appears as the first term between brackets. The remaining summation in k therefore does not include 0 ("/0" as shown). The influence of the parameter n is, as we wanted to prove, to introduce a periodicity depending on the amount of flux confined by the current ring, and the regularized energy is therefore periodic in n. Therefore, Z (1– s) is given as:

$$\sum_k \{(k-n)^2 + m'^2\}^{-(1-s)/2} =$$

$$= \frac{2}{\Gamma\left(\frac{1-s}{2}\right)} \int_0^\infty t^{\frac{1-s}{2}-1} \left(\sum_k e^{-(k-n)^2 t - m'^2 t} \right) dt =$$

$$= \frac{2\sqrt{\pi}}{\Gamma\left(\frac{1-s}{2}\right)} \int_0^\infty t^{-\frac{s}{2}-1} \left(\sum_k e^{-2\pi i k n} \; e^{-\frac{\pi^2 k^2}{t} - m'^2 t} \right) dt =$$

$$= \frac{2\sqrt{\pi}}{\Gamma\left(\frac{1-s}{2}\right)} \left(\frac{\Gamma\left(-\frac{s}{2}\right)}{m'^{-s}} + 2\pi^{-s/2} \sum_{k/0} \left(\frac{k}{m'}\right)^{\frac{-s}{2}} K_{\frac{s}{2}}(2\pi m' k) e^{-2\pi i k n} \right) \qquad (10)$$

for s → –1. From eq. (9), the "Reg" summation in (8) becomes $\left(\pi^{\frac{2s-1}{2}} / \Gamma\left(\frac{s}{2}\right)\right) \Gamma\left(\frac{1-s}{2}\right) Z(1-s)$, and the exponential produces a cosine term.

Since $\Gamma(-1/2)= -2\sqrt{\pi}$ we see that the regularized sum is negative, corresponding to energies lower than U_0. In the fitting to the data we will admit that both m' and u_0 are adjustable parameters.

Figure 1 shows the data for all baryons in Tables I and II of ref.[2],, and the plot of eq.(8) regularized by eq.(10), for u_0 = 3.96 and m'= 0.347 (corresponding to m_0= 2.88 m_p and U_0= 3710 MeV). The energy 3710 MeV would represent the sea of excitations from which the baryons would evolve.

3. Analysis and Conclusions.

This model presents an entirely new result, which is the proposal of a parent state at 3.71 GeV. WE have found evidence for this proposal from the populations of protons in cosmic rays[3].

In Figure 2 we show data for the *number* flux of protons plotted as E (dN/dE) against kinetic energy E in GeV, from cosmic rays below 10 GeV kinetic energy, taken from the upper left corner of Figure 1.1 of ref. [3]. Below about 2 GeV kinetic energy there is an approximate plateau. From 2 GeV on, a marked decrease in the flux of protons is observed. We have obtained the actual functional relations in the original double-log plot, to calculate the number N of particles in units of $(\mathrm{m}^2\ \mathrm{sr\ s})^{-1}$ for several energy intervals. Assuming from Fig. 3 below that the plateau in E (dN/dE) would begin at about 0.1 GeV and goes up to 3 GeV, we obtain N= 6800 by integration in this interval. Beyond 3 GeV the ordinate decays as $E^{-3/2}$. Therefore, one obtains by integration N= 1100 between 3 and 10 GeV, and a very small N= 204 between 10 and 100 GeV. That is, well over 80% of the protons have energies below about 3 GeV, and the numbers beyond 10 GeV are negligible in absolute terms in spite of the great interest on them from the high-energy physics standpoint.

A related effect breaks Cooper pairs in superconductors if their kinetic energy gets greater than the pairing interaction provided by phonon-intermediated coupling.

Figure 3 shows a plot of the estimated (from collected data) *energy* distribution for the interstellar flux of protons [3], which peaks exactly at 2.7 GeV. Such peak is clearly due to the marked decrease of the number flux of protons beyond the peak energy.

A prediction of this theory is that if the energy difference of 2.7 GeV between the vacuum background energy level and a proton rest energy is surpassed by energetic protons, such particles would not be found in nature since the vortices would become unstable. In reality, a marked *decrease* in the flux of cosmic rays protons is indeed observed beyond 2.7GeV kinetic energies. The fact that protons are still observed in small amounts even at extremely high energies is clearly associated to binding interactions in the range below the size L of the current loop in the model (10^{-16} m), between constituents inside these particles not considered in the vortex picture. The electrodynamic vortex-model is nevertheless accurate enough to probe the properties of the background vacuum state, and provide valuable new information in the form of the energy level U_0. At the same time its limitations can be traced to the need for detailed consideration of the inner structure of baryons constituents at certain dimensions and energy range. Further investigations are clearly needed in the lower range of cosmic rays energies.

References

1. O.F.Schilling, Annales de la Fondation Louis de Broglie, **43**-1, 1 (2018).
2. O.F.Schilling, Progress in Physics, **15(**3**)**, 185 (2019), and references therein.
   Correction: In eq. 7 one should include "+ m_p^2 c^2" between the curly brackets.
   http://www.ptep-online.com/2019/PP-58-08.PDF
   See also previous work by the author in vixra.org.

3. T.K.Gaisser, R. Engel and E. Resconi, Cosmic Rays and Particle Physics, Cambridge, 2016.

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Figure 1: Comparison of baryons masses calculated from eq. (8) as a function of confined flux *n* , with data for octet (open circles) and decuplet particles (m_t used, stars). The relation between these quantities(data points) agrees quite well with the field-theoretical calculations (curve) of mass as function of *n* from eq.(8). Nucleons are on the basis of the figure(see [2]).

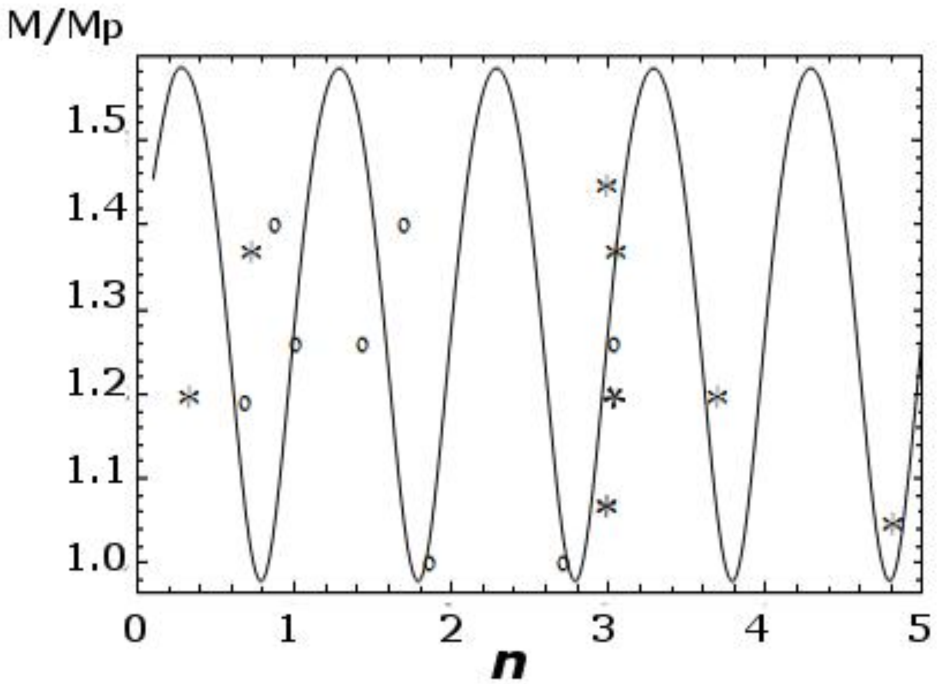

Figure 2: Reproduction of the upper left part of the double-log plots in Figure 1.1 of ref.[3] (linearized scales are adopted here). The *number* flux of protons in 10^3 m^{-2} (sr. s)$^{-1}$ units is plotted against the protons kinetic energy in GeV. The vertical line is placed at the value of *K* that corresponds to total loss of the vortex energy advantage compared to the vacuum parent state(see [2]). The solid line is a guide.

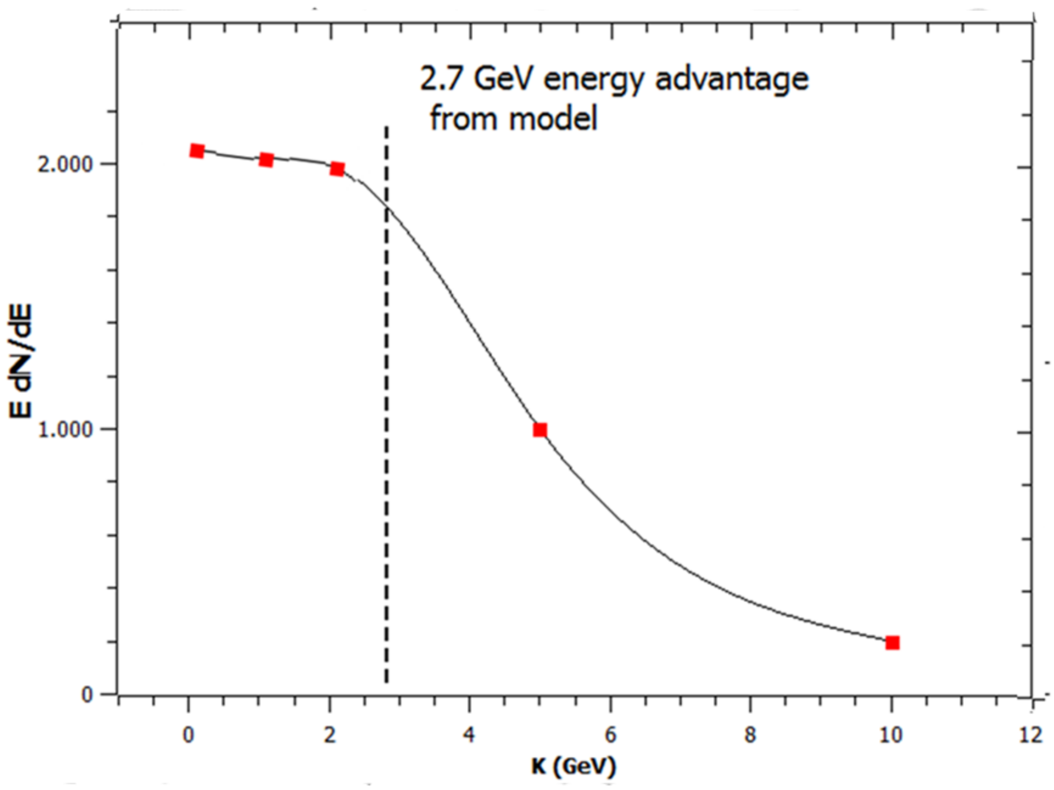

Figure 3: Estimated *energy* flux distribution of interstellar protons in cosmic rays, which peaks at exactly K= 2.7 GeV[3].