Non-perturbative resonances of the electromagnetic interaction

Andrea Gregori[†]

Abstract

We discuss enhancements of the cross section in particle-antiparticle scattering, of a type not expected in quantum field theory, however predicted in the quantum gravity theoretical framework discussed in Refs [1, 2, 3]. The first events of this kind are to be found in the energy range between some 111 GeV and 130 GeV, with a stronger peak around 125-126 GeV, and weaker ones around 114 GeV and 130 GeV. The strongest peak turns out to correspond to the resonance which is usually interpreted as due to a Higgs boson, whereas the other ones are compatible with astrophysical observations devoted to inspect the presence of Dark Matter. This approach provides a no-Higgs, no Dark Matter explanation for the observed excess of photon production, which does not result from fine-tuning of parameters chosen ad-hoc in a particular model, but naturally fits within the theoretical scenario described in [1]–[3]. Further peaks are expected to appear at higher energy. They show up separated from each other by energy steps much wider than a typical resonance width. Being isolated and of moderate intensity, they may be more difficult to single out over the statistical fluctuations of background events.

[†]e-mail: gregori.research@gmail.com

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1 Introduction

It is well known that, owing to the strong interaction, quarks combine into composite particles (proton, neutron, etc...) which are much heavier than the sum of the masses of the free quarks. The binding energy of the quarks is larger than the sum of their rest energies (their masses), and, owing to the strong coupling, it is entirely interpreted as mass of the composite particle. In principle, this is not much different from what happens, at a larger scale, to the particles constituting an atom. However, in that case the interaction that glues the single particles, the electromagnetic interaction, is weak, and the total mass is almost identical to the sum of the masses of the single electrons, protons and neutrons. The situation of the colour force is somehow "S-dual" (i.e. it has inverse strength of the coupling) to the one of the electromagnetic interaction. Could we have a regime of strong electric force, we would find composite states held together electromagnetically. However, at experimentally relevant scales, the electromagnetic coupling is weak. According to the usual rules of quantum field theory, there seems to be no room for such a kind of situation to be realized, not even artificially as a temporary state. In a String or M- Theory context one in principle has S-duality of the coupling, but this only matters at energies around, or above, the Planck scale, according to the specific model and approach. It is assumed that, in order to reduce the theory to a quantum field theory effective model, at lower energies S-duality is broken. Acting like a projection onto just one part of the initial theory, this breaking leaves no trace of S-duality at low energy scales. However, despite the success of the phenomenology of elementary particles based on the Standard Model, there is no deep reason to expect that even low-energy physics must be *entirely* encoded within a quantum field theoretical framework: a model based on quantum field theory could just constitute a *truncated* representation of the low-energy physics. The breaking of S-duality would in this case be a projection onto just a part of the effective low energy physics, rather than leading to the entire low energy effective world. A low-energy effective model based on quantum field theory would then be an incomplete approximation of the whole low-energy theory, which would show even at low energy scales aspects ignored by quantum field theory. This "new-physics" could already lie before our eyes, not recognized as such because of our attempts to interpret any phenomenon whithin appropriate modifications of the Standard Model, an attitude that sometimes seems to generate more problems than it is supposed to solve.

If we look at the history of physics, we see that in general the limitations of a theoretical framework are not overcome by just "extending" the theory through small corrections based on the same conceptual approach, but through a deeply different approach to the whole set of physical problems. For instance, in the case of quantum mechanics, the classical theory is not really obtained by taking a simple limit: passing from the one to the other involves a conceptual jump, the limit taken over the value of the Planck constant $\hbar$ being not simply a formal operation, but involving a re-interpretation of all classical quantities within the conceptual framework of quantum mechanics. Learning from the history of physics, we can imagine a similar situation for the case of going beyond quantum field theory. It could be that the theory which correctly unifies quantum mechanics and general relativity is based on physical concepts that only in a loose sense "reduce" to the ones of quantum field theory. In this case, we should not expect the low-energy effective quantum field theory to proceed as a simple limit taken on the unifying theory. Or, at least, to not appear as such when seen from the point of view of a conceptual framework based on quantum field theory.

In the wake of this idea, in Refs. [1, 2, 3] we introduced "from scratch" a theoretical scenario in which neither quantum mechanics, nor general relativity, are assumed "ab initio", among the basic principles of the theoretical construction: they turn out to be themselves consequence of more general assumptions, and show up incorporated into something more fundamental, defined in terms of what could be called "codes of information". The physical content of this scenario is obtained through the interpretation of the universe of codes of information in terms of distributions of energy units along a discrete space, and therefore, in the continuum limit, of geometries. String theory, and M-theory, turn out to be approximations recovered in certain limits and under certain conditions. However, differently from string and M-theory in their general formulation, this scenario turns out to be highly predictive, and in principle it allows to compute any physical quantity as a function of just one parameter, the age of the universe, which is also the only free parameter of the theory. Indeed, in Ref. [3] we have discussed several explicit computations of physical quantities, such as the masses of the elementary particles, the values of their couplings (including the fine structure α), and cosmological parameters, such as the cosmological constant, producing a very good qualitative and quantitative agreement with the experimental results. The absence of freely adjustable parameters makes of any comparison with experimental results a test potentially able to rule out the entire construction. On the other hand, any agreement is a highly non-trivial support. These facts, together with the absence so far of any disagreement, suggest that this approach deserves to be seriously considered as an alternative theoretical framework in which to arrange possible manifestations of "new physics". It is in this light that we want to consider the question weather temporary states equivalent to electrically strongly coupled virtual particles can show up at sub-Planckian energy. Although ruled out in a quantum field theory framework, this question seems to be justified by certain experimental results, that we are going to discuss.

In the theoretical framework we are going to consider, the universe is encoded in a partition function given by the sum over all possible geometries [1], weighted by their combinatorial entropy. This means that the weight of any geometry is proportional to the volume of the symmetry group of the geometry itself. Geometries can be grouped into sets according to their total energy content. Each set corresponds to a "universe" with a given amount of total energy. This introduces a natural order, by inclusion of sets, that turns out to correspond to a time ordering, the time parameter being the total energy. In this way one naturally obtains a time path through "universes", each one encoded in a partition function given by the weighted sum over all the geometries at a given amount of total energy. The collection of these sets together with their time ordering is interpreted as the history of the universe, the total energy playing also the role of age of the universe. The latter turns then out to be the only free parameter of the whole construction.

We are not going to quote here the details of this set up. We just recall that, although the phase space contains geometries in any space dimension, the statistically preferred space dimension turns out to be precisely three, the actual dimension of our physical world. On the other hand, the fact that not only the combinatorically favored configuration, but an infinite number of them contribute to the partition function, and therefore to any physical observable quantity, results in a scenario that possesses the characteristics of a physical quantum universe. A detailed inspection shows that, at large volume, far from the Planck scale, one recovers all the fundamental aspects (general relativity, quantum field theory, the known spectrum of elementary particles and their interactions) of the physics we know. For a thoroughful discussion we refer the reader to Refs. [1, 2, 3]. Contact with the usual parameters entering an effective action of elementary particles is attained by taking the limit to the continuum. However, the perspective is here reversed as compared to the usual approach, in which the discrete is viewed as an approximation of the continuum: here it is the continuum what has to be viewed as an approximation of a world basically defined on the discrete.

Passing from a history of geometries (i.e. distributions of energy in space) to a description in terms of the usual degrees of freedom of fundamental physics involves the identification of local "energy clusters", and their parametrization in terms of elementary particles and their interactions. Particles arise as a particular type of energy packets. Their masses are therefore related to weights of symmetries (i.e. volumes of symmetry

[1]Geometries are here defined as a particular space distribution of units of energy in a discrete space (the lattice scale is then identified with the Planck scale). Any such a distribution can be viewed as a binary sequence of occupation numbers of the type 0, 1, hence the association to a universe of binary codes of information.

groups) of geometries. Also the scattering amplitudes are given as ratios of weights, namely the ratio of the weight the average local geometry around the experiment has after the collision to the one it has before. As a consequence, the interaction couplings too are given as ratios of weights, i.e. as ratios of volumes of symmetry groups. In particular, the hierarchy of masses of the elementary particles can be put in relation to a chain of symmetry breakings: their ratios turn out to be related to the relative volumes of group cosets, in first approximation expressed as functions of the $SU(2)$ coupling. One can intuitively make sense of this behaviour by observing that more interacting particles are in general heavier: the quarks interact through all the known interactions, and are generally heavier than the leptons. Among leptons, the lightest ones are the neutrinos, which feel only the weak interaction. From the point of view of our theoretical approach, this is directly related to the fact that more interacting particles are "more present" in the phase space, in the sense that they have more possibilities of being at play in the phase space of all the events. Of course, this has to be taken as a rough picture, that doesn't account for what seem to be single departures from this scheme (for instance the fact that the lightest quarks are lighter than the heaviest leptons). Indeed, a precise determination of the various mass ratios requires a detailed analysis of the phase space. Anyway, the basic idea is viewing the entire spectrum of particles as obtained through a "cascade" of reductions of symmetry, which concerns not only the symmetries associated to the interactions, but also internal symmetries. Breaking the latter ones produces a differentiation, reflecting in a mass hierarchy, between families of particles. At the end of the game, all particles have a different mass. A thoroughful investigation of the phase space and the evaluation of masses have been done in Ref. [3], obtaing results in agreement with the experimental measurements. Here we are not going to repeat the arguments, because, for the purpose of the present discussion, we are just interested in sketching the idea. The relation between masses and couplings is particularly simple for weak interacting particles, in particular the lightest particles of the spectrum, the neutrinos, which feel just one type of interaction (besides the gravitational one). In this case, the ratio of masses is simply given by the coupling of $SU(2)$, according to the relation:

$$\frac{m_1}{m_2} \sim g^{-2}_{SU(2)} \, .$$

In the case of particles which feel also other types of interaction (electrically charged leptons, quarks), the relation is similar:

$$\frac{m_1}{m_2} \sim g_G^{-2} \, , \tag{1.1}$$

where $G = G_{12} \equiv G_1/G_2$ is the coset of the symmetry groups G_1 and G_2 corresponding to particle 1 and 2, and as coupling one takes the overall effective coupling strength (in this scenario one basically does not deal with bare quantities but with full physical quantities, because the partition function directly encodes the physics of an interacting world, and this approach is non-perturbative in its definition). According to the relation 1.1, the higher the energy gap between two states, the larger is the breaking of symmetry. If two mutually interacting states had the same weight (in other words, the same volume of occupation in the phase space), they would basically be the same state [2]. This would also trivially mean unbroken symmetry: the interaction would be "strong" ($g = 1$), in the sense that, being the states undistinguishable, one could interpret the situation as a sort of "steady-state" characterized by their continuous exchange. Therefore, the larger the ratio of masses, the larger is the breaking of symmetry, and the lower is also the interaction probability (weak coupling). One can understand why things are going in this way by thinking that, keeping fixed the overall number of degrees of freedom, when the symmetry group is larger we have less states (a smaller spectrum of elementary particles) which transform under a larger symmetry group [3]. The occupation in the phase space of each of these states is therefore larger than the occupation of each state after the breaking of symmetry, because the orbit of their group is larger. In this theoretical framework, where energy distributions sum up to build the physical content of the universe, states which are counted more times are by definition heavier. In this case, the states transforming under the unbroken symmetry group are heavier than those with broken symmetry, by an amount proportional to the ratio of the volumes of the orbits of the unbroken to the broken group.

[2] In our scenario, occupation volumes are in bijective correspondence to the full information of a state, not just its rest energy.

[3] We are talking here of striktly unbroken symmetry.

In the philosophy of this approach, two particles of mass m_1 colliding at a center-of-mass energy $E_{\rm c.o.m.} \sim 2 \times (1/g^2) \times m_1$, at the point of collision would behave like two particles of mass $m_2 = m_1/g^2$. This implies that, at this center-of-mass energy, we should expect an increase of the scattering amplitude, due to the extra channels that precisely at this energy concur to the process: besides those of the particles with mass m_1, also those of the particles with mass m_2. On the other hand, particles with mass m_2 can be viewed as derived from particles with mass m_1 by "eating" the degrees of freedom of one group factor G, which now contribute to the internal symmetry of particles with mass m_2, thereby increasing their mass. It is somehow a freezing of the degrees of freedom by going to the strong coupling, and, indeed, so can it be interpreted, if one considers that the eaten volume is precisely proportional to the S-dual of the coupling in the weak coupling regime, $\frac{1}{g^2} \sim \alpha^{-1}$. Consider now the collision of two electrically charged particles of opposite electric charge. Although a rotation by an element of the symmetry group corresponding to the electromagnetic interaction does not relate states of different mass, like instead the $SU(2)$ transformation does, at a center-of-mass energy larger than the rest mass of the colliding particles by a factor α_γ^{-1} we are in a situation of effective S-dual coupling, that reminds the one we have just considered. It is therefore reasonable to ask whether also in this case should we expect to see an enhancement of the scattering amplitude, due to the appearence of a state, this time a virtual state, of enhanced rest energy corresponding to the volume of the frozen degrees of freedom of a $U(1)_\gamma$ (the electromagnetic group) factor. In this paper we are precisely going to discuss under what conditions this situation can be realized. We will see that in our theoretical scenario there are conditions under which such a kind of effect indeed occurs. The first case of such an enhancement of the cross section shows up around [111-114] GeV, followed by other ones at slightly higher energy, with peaks around [124-126] GeV and $\sim$ 130 GeV. All these are expected to manifest themselves through an excess of $\gamma\gamma$ production. The strongest one is around 125 GeV, because it is produced as the sum of more than one such process. This is the resonance line already considered in section 7.1 of Ref. [3], which appears to coincide with the one observed at LHC in proton-antiproton scattering, that one would like to explain as due to the appearence of a Higgs boson ([4, 5, 6]). The other two lines are weaker, nevertheless there is some evidence of photon lines at these energies coming from astrophysical observations [7, 8, 9, 10, 11].

2 Ratios of volumes in the phase space

Let us focus our attention on the electromagnetically charged particle-antiparticle pairs. We want to see more in detail under what conditions it is possible to produce an effective strongly coupled equivalent state, leading to an increase of the scattering cross section. In order for this to occur, it is necessary that the gauge degrees of freedom of a pair of independent particles can be interpreted as collapsing, due to the strong coupling, to a configuration in which there is no gauge group at all (frozen gauge degrees of freedom): this configuration is therefore equivalent to the one of an electrically neutral state. In this case, the factor of the volume occupied in the phase space by the two-particles configuration corresponding to the gauge degrees of freedom, $V_{(\rm particle\,1)} \times V_{(\rm particle\,2)}$, is reduced to 1 (just one possible configuration, no enhancement proportional to the size of the orbit of a symmetry). The only possibility for this to occur is that the scattering does involve hadrons, either as virtual states, e.g. when in the collision of a e^+e^- (or other lepton-antilepton) pair one creates a $p\bar{p}$ (or heavier hadron) pair, or as colliding particles, e.g. a collision of a $p\bar{p}$ pair, where one creates either lepton pairs (e^+e^-, $\mu^+\mu^-$ or $\tau^+\tau^-$) or even other hadron pairs. Incoming and virtually produced particles must then couple in order to form electrically neutral compounds that contain *more than two spinors*. For instance, if we let to collide a $p_{\rm in}\bar{p}_{\rm in}$ pair, it must be possible to create an $e^+_{\rm virtual}e^-_{\rm virtual}$ pair, which forms bound states of the type $[p_{\rm in}e^-_{\rm virtual}]$ (and/or their charge-conjugates), as shown in figures 4 and 5. The reason is the following. In a lepton-antilepton pair the electromagnetic group acts in opposite way on the two states of the pair, by a transformation depending on a parameter β: $\bar{\psi}\psi \to {\rm e}^{-{\rm i}q\beta}\,\bar{\psi}\psi\,{\rm e}^{{\rm i}q\beta}$, where q is the actual value of the electric charge Q. The non-effectiveness of the overall transformation is attained as the result of an exact point-wise cancellation all over along the orbit of β, a situation effectively equivalent to having zero electric charge, like in a neutral state: $\phi_{Q=0} \to {\rm e}^{{\rm i}0\beta}\phi_{Q=0}$. The volume of the orbit, $V(\beta)$, is the span of all the values of the parameter β, and is clearly the same for any value of the electric charge Q, so that in both the cases it is the same: $V_q(\beta) = V(\beta)$, $\forall q$. Therefore, when the particle's compound can be considered equivalent to just one neutral particle, there is no change in the volume of the orbit in going to the strong coupling [4]: the volume of the group passes from being $V_{Q=q}(\beta)$ for the lepton-antilepton pair to $V_{Q=0}(\beta)$ for the neutral bound state. On the contrary, in the case of the lepton-hadron compound, like the $[p_{\rm in} e^-_{\rm virtual}]$ pair, the effective charge cancellation occurs through a sum of Lie-group parameters $\beta_{\rm i}$:

$$\beta_{u_1} + \beta_{u_2} + \beta_d = -\beta_e \,. \tag{2.1}$$

There are therefore two more free parameters than in the case of the lepton-antilepton pair. As compared to the case of a single neutral particle, the set of two particles has two group volume factors more. At the energy of effective strong coupling the same volume of occupation in the phase space can be equivalently viewed as corresponding either to two particles, pointwise paired (p, e), or to a configuration with a single neutral particle (the strongly bound $[p - e]$ compound). In this second case, the volume occupied in the phase space has to be interpreted as entirely due to rest energy (= mass) of the neutral particle. The mass gap between the neutral particle and the two single particles corresponds to the volume of the missing electromagnetic symmetry group, namely the *product of the volumes*, corresponding to two $\beta_{\rm i}$ parameters: $M_{p+e}/M_{[p-e]} \sim [V(\beta)]^2$. In order to see the relation to the coupling g, we must consider that, as it is defined on the Lie algebra, the coupling g works as unit of measure of the values the Lie parameter (in gauge theory promoted to local field) can assume along a period of the orbit:

$$g \times \text{Volume} \simeq 2\pi \,. \tag{2.2}$$

The rest energies of the two configurations stay therefore in a ratio given by:

$$\frac{M_{p+e}}{M_{[p-e]}} \simeq g^2 \,. \tag{2.3}$$

In both these expressions we omitted the exact normalization of the coupling. Indeed, this is fixed by requiring that, by definition, the ratio of phase space amplitudes is precisely the coupling $\alpha \stackrel{\rm def}{\equiv} \frac{g^2}{4\pi}$ (see Ref. [3]). Relation 2.3 can be expressed as:

$$M_{[p-e]} \sim \alpha^{-1} M_{p+e} \,. \tag{2.4}$$

This situation has to be compared with a typical expression of binding energy in the weak coupling regime. For instance, in an hydrogen atom the electronic energy levels, which refer to standing waves and are derived from the Coulomb potential, therefore a second-order effect in powers of the coupling, are proportional to $[m_e]\alpha^2$. Here we have instead a first order effect in the S-dual of the coupling: α^{-1} vs. α^2. It must be stressed that this effect has no counterpart in quantum field theory: it can only be justified in a theoretical framework in which amplitudes are related to the combinatorial probabilities at a certain amount of energy. The description we gave in terms of the ordinary concepts and degrees of freedom of quantum field theory has to be considered as a kind of "semiclassical" approximation allowing to figure out what is going on and translate it in familiar words.

3 Why a resonance

Let us now consider the dynamics of a particle-antiparticle scattering in our theoretical scenario. As seen from a geometric point of view, what we have is a cluster of energy around the scattering point. When the amount of energy allows the interpretation of the cluster not only as a set of weakly interacting elementary particles, but *also* as bound state of strongly coupled particles, the combinatorial possibilities increase. This implies a larger volume in the phase space (i.e. a larger volume of the combinatorial group of the distribution

[4] This theoretical setup is originally defined on the discrete space, and determining volumes is in principle a simple thing. The volume of a discrete group is simply the number of its elements. However, the contact point with the physics we experience, and test, occurs in the limit to the continuum, where we recover the familiar concepts of field theory, and gauge groups. In this limit, things are no more so obvious. But, since we are eventually interested in ratios of volumes, we don't really need absolute values of group volumes, but relative ones. In this case, it is still natural to think the volumes of compact Lie groups as given by the volume of the space of their parameters, and therefore determine ratios of volumes as the ratio of the number of generators of the Lie algebra (the ratio of dimensions). These in turn have been successfully used in Ref. [3] in order to determine the strength of the gauge couplings.

of energy). In our theoretical framework, this translates into a relation similar to 2.3, this time relating to the full effective coupling of the interaction, $M_i/M_f \approx g^2_{\rm eff}$, the ratio of the whole weight of the initial configuration to the weight of the final scattering products. Adding new combinatorial possibilities to the initial configuration before the scattering, i.e. increasing M_i, leads to an increase of the effective coupling, and therefore of the scattering amplitude.

If we want to look at the details of what is going on, and recover the familiar description in terms of elementary particles and their interactions, we must leave the phase space and look at the time evolution of the process. In the phase space, geometries are summed at fixed time to contribute to the average geometry at any time of the physical evolution. Scattering amplitudes are instead obtained by summing up scattering events along a certain interval of time, corresponding to the duration of the experiment [5]. It turns out that the energy $E = \alpha^{-1} M_{p+e}$ is a critical energy, at which new possibilities of realizing the scattering open up. Consider a proton-antiproton scattering. At the critical energy, the scattering amplitude receives comparable contributions not only from a first order process like the direct $p\bar{p} \to \gamma\gamma$ scattering: also channels which in an ordinary perturbative expansion over the value of the coupling would be suppressed contribute in this case with comparable strength. This occurs only at the critical energy, when an interpretation in terms of strong coupling opens up: out of this point, these channels are ordinary higher-order processes, and are therefore suppressed. The additional channels involve the creation of a lepton-antilepton pair (e.g. electron-positron pair). In the usual perturbative approach, represented by Feynman diagrams in terms of interactions and propagators of free fields and particles, these are second- and third-order processes, as illustrated in figures 2 and 3. However, at the critical energy of effective strong coupling there is no g^2 and g^4 suppression, because the proton-electron pairs are strongly bound into one state. As a consequence, there is no gauge symmetry with coupling g mediating the interaction among particles within the bound state (see figures 4 and 5). Therefore, these decays into pairs of photons sum up with a strength comparable to the one of the first-order, direct $\to \gamma\gamma$ process. Above the critical energy, owing to mismatching momentum account we can no more interpret the energy cluster as the bound state plus the other free particles. The reason is the following: At the threshold the total energy equals the sum of the masses of the involved particles. Above this energy, there must be also some momentum. But the existence of a bound state, in this case a (pe) bound state, implies that p, e, p^- and e^+ have *all* the *same* speed, whereas the first two are paired to a higher mass state. This is incompatible with energy-momentum conservation; above the critical energy the bound state channels are suppressed once again, as they were below the threshold.

To summarize, the scattering amplitude has a peak centered around the critical energy of effective strong coupling, characterized by an excess of typically leptonic decays, $(\ell\bar{\ell} \to \gamma\gamma)$. These processes are illustrated in figures 1, 2, 3, 4 and 5. Picture 1 shows the basic, first order $p\bar{p} \to \gamma\gamma$ process, which is going to be reinforced at the critical energy by the contributions illustrated in figures 2–5. They show scattering channels which, from a field theory point of view, are of higher order in the coupling α. They are therefore suppressed, except at the critical energy, where one can interpret the virtual components as forming a strongly coupled compound, accompanied by the disappearence of the gauge symmetry associated to their interaction [6]. At this point, and only at this point, they are no more of higher order (i.e. no more suppressed). The phenomenon we have described is not a property of just the $p\bar{p}$ scattering. The enhancement of the cross section occurs, under the same conditions, and at the same critical energy, also if in the diagrams 1–5 one exchanges proton and electron: in lepton-antilepton pair scattering, via creation of a virtual proton-antiproton pair, in which one or both the hadrons couple in a strong way to the electron

[5] A conceptual difference between this approach and the scattering probabilities as they are defined in quantum mechanics needs here to be pointed out: in the traditional approach to quantum mechanics, probabilities are defined at any instant of time, and are compared with experiments performed along a time interval. Here, speaking in terms of probabilities is not much appropriate: in this scenario physics is neither deterministic nor probabilistic. It is rather "determined", as the result of an infinite number of contributing terms. It is precisely the infinity of contributions, and the impossibility of interpreting all of them in terms of "classical" geometries, what forcedly leads to an interpretation in terms of probabilities. In this scenario, speaking in terms of probabilities is considered a (unavoidable) conceptual artifact, allowing to encode, and predict, experimental results, because a parametrization in terms of the usual concepts of particles, masses, couplings, is only allowed above a certain scale (of space, time, energy). For a discussion of the dynamics ruling physics in this theoretical approach, and how an effective quantum theory is recovered, see Ref. [1], section 4.

[6] Keep in mind that, despite their representation in figures 1–5, these processes are not to be interpreted as depicting Feynman diagrams within a field theory context.

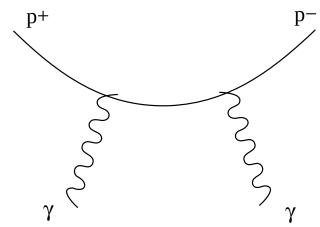

Figure 1: Representation of a direct $p\bar{p} \to \gamma\gamma$ scattering channel (the single channels ($u\bar{u} \to 2\gamma, u\bar{u} \to 2\gamma, d\bar{d} \to 2\gamma$) are here collectively indicated by just one proton line).

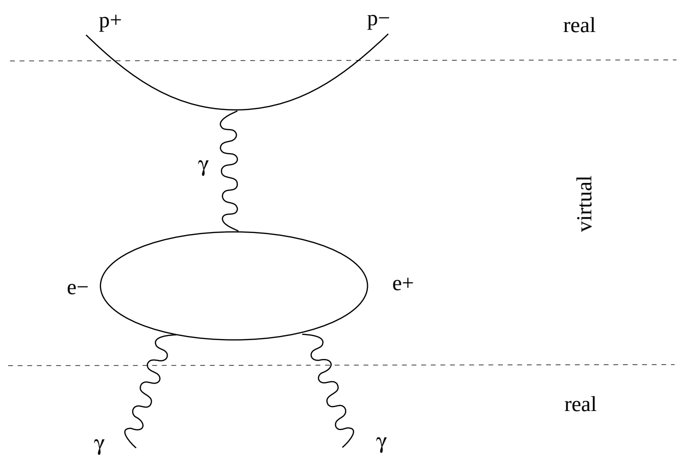

Figure 2: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual e^+e^- pair creation.

and/or the positron. Analogous considerations can be done with the charged leptons μ and τ at the place of the electron. The peaks of cross section they produce by strongly pairing to protons occur at higher energy: $E_c \sim E_{\bar{p}} + \alpha^{-1} \times (m_p + m_\mu)$ and $E_c \sim E_{\bar{p}} + \alpha^{-1} \times (m_p + m_\tau)$ respectively.

In order to compute the critical energy values, we must insert in the expressions not only the current values of the masses of the particles, but also an appropriate value for the electromagnetic coupling. In order to find it we proceed as follows. In all the cases in which a lepton-pair is produced, the process occurs at the level of free particles, namely, it involves just the electromagnetic part of the interaction. For an estimate of the energy at which to run the electromagnetic coupling, we consider therefore the typical energy of the free particles involved, the lepton and the free quarks. In the case of electrons pair, the typical energy of the process is therefore the MeV scale. The electromagnetic coupling is run to this scale according to the behaviour derived in Ref. [3], i.e. logarithmically up to the Planck scale, where it is 1. The scale of the heaviest quark is about one order of magnitude higher than the electroweak scale, and 21 orders of magnitude lower than the Planck scale ($\sim 10^{19}$ GeV). The value of the inverse coupling at that scale is therefore around $\frac{21}{22} \times 137$ [7]. For this value of the coupling we obtain a critical energy at $\sim 0.939\,\mathrm{GeV} \times 137 \times \mathcal{O}(21/22) + 0.939\,\mathrm{GeV} \approx 124 \div 126$ GeV. This is only an approximate estimate, the uncertainty depending on our lack of precision in the choice of the energy scale for the computation of the renormalization of the coupling: should it be an average scale between that of the *up* and *down* quarks, or the sum of the quark masses plus the electron's mass? The second option, which corresponds to choosing as energy scale the total energy of the involved bare particles, intuitively a reasonable choice, is the one that gives as critical energy 125 GeV. The production of a virtual $\mu\bar{\mu}$ pair occurs at slightly higher

[7] We recall that in this theoretical framework the values of masses and couplings are not freely adjustable parameters, but are computed as functions of the only free parameter of this scenario, the age of the universe. Comparison with just one experimental quantity is enough to fix its present value, and to consequently derive the value of all the remaining physical quantities.

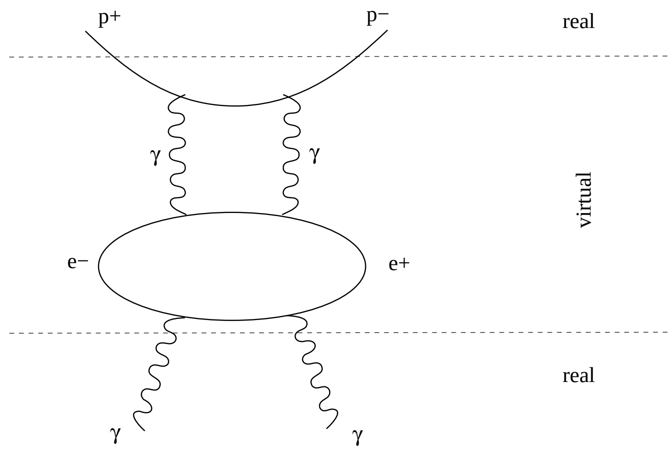

Figure 3: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual e^+e^- pair creation.

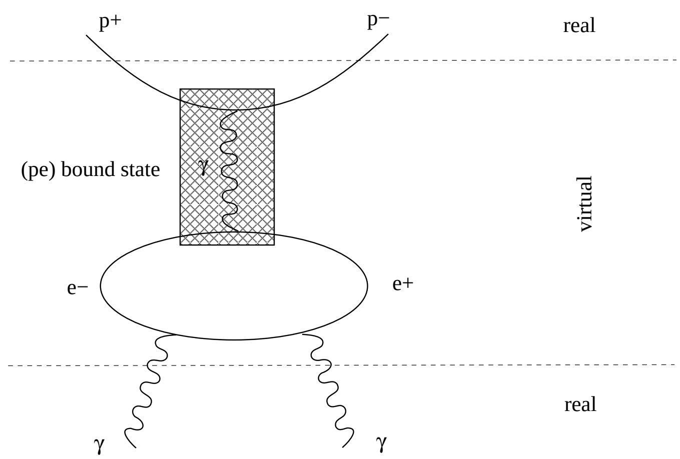

Figure 4: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual e^+e^- pair creation at the (pe) bound-state critical energy.

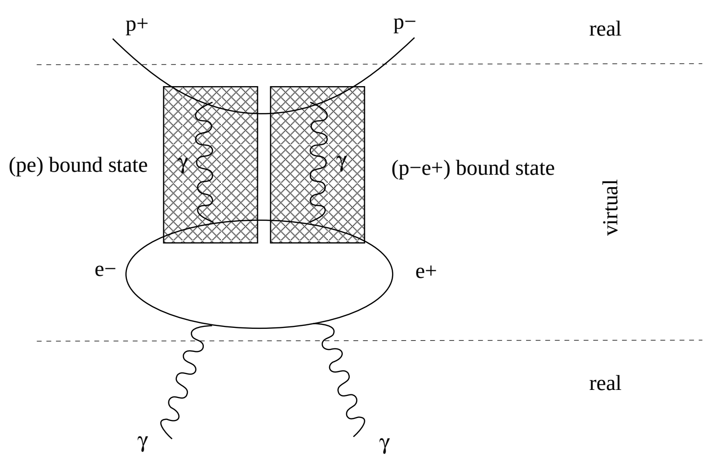

Figure 5: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual e^+e^- pair creation at the $(pe)(p^-e^+)$ double bound-state critical energy.

energy. Inserting the value of the muon mass, and using for the evaluation of the electromagnetic coupling the 100 MeV scale, we find as energy threshold $E \sim 1,040\,\text{MeV} \times 137 \times \mathcal{O}(20/22) + 1,040 \approx 130 \div 131$ GeV. The further leptonic peak, corresponding to a $(p\tau)$ state, occurs at much higher energy ($m_\tau \sim 1,777$ GeV, implying ~ 324 GeV as critical energy). Enhancements of the cross section at higher energies are produced when both the lepton-hadron and the anti-lepton–anti-hadron pairs are at a virtual strong coupling. These peaks are to be found at about twice the energy of the single-pair peak.

Besides binding quarks with leptons, there is also the possibility of forming virtual states made of pairs of quarks electromagnetically strongly coupled with other quarks. These can be a subset of the quarks and anti-quarks from the colliding proton-antiproton pair, or pairs formed from quarks of the incoming proton (and/or anti-proton) and virtual quarks instead of virtual leptons. In this case one forms mesonic-like states. The lightest resonances are to be expected from the creation of pion-like bound states, obtained producing virtual $u\bar{u}$ and $d\bar{d}$ pairs, in which each virtual quark couples electrically to a corresponding quark with opposite charge in the incoming proton or antiproton. Also these states mainly decay into pairs of photons. The evaluation of the energy thresholds is however in this case affected by the fact that now incident and virtual quarks can interact among themselves also through the strong force. The energy scale of the process, the energy at which the inverse of the electromagnetic coupling must be run, is arguably no more that of the bare quarks. As discussed in Ref. [3], all the states that feel this type of interaction are "attracted" by the energy scale of the only state which is neutral under all the elementary forces: a compound of proton-neutron-electron-neutrino, that can form a kind of "steady state" in equilibrium for all the three fundamental interactions (strong, electromagnetic, and weak). We don't have here the possibility of going through the arguments leading to this result, which is basically equivalent to the computation of the neutron's mass. For a discussion we refer the reader to sections 4.3.6, 5.3, 5.5 and 5.6 of Ref. [3]. In this theoretical framework the evaluation of this mass scale proceeds from first principles, and it is at the base of the determination of all the scales. Like all energy scales, also this one is not fixed, but runs as a power of the inverse of the age of the universe. At present time it is of the order of 2 GeV [8]. As it was discussed in Ref. [3] (sections 5.5-5.6), the attraction of this scale is more effective for stable quark compounds (the proton-neutron system of above), whereas unstable states must be treated as perturbations. In order to find out what is the right energy scale at which to evaluate the effective electromagnetic coupling to be used in our computations, we must consider that in this theoretical scenario physical parameters are average quantities obtained from a superposition of geometries. In this case, we can figure out that we have a superposition of configurations in which the involved quarks interact partly in triplets to form protons, partly in pairs to form pions. For a rough evaluation of the effective value of the electromagnetic coupling we choose therefore an intermediate scale between the one of the proton and the one of the virtual meson. Owing to the multiplicative structure of the phase space, we decide for a geometric mean, $\langle E \rangle \approx \sqrt{E_p \times E_\pi}$. This choice should lead us not too far away from the correct value.

We consider now the electrical coupling of quarks and anti-quarks. In this case, at the critical energy we gain even powers of the coupling g: 2 or 4, i.e. one or two α^{-1} factors for each quark pair. For instance, in the case of a $u\bar{u}$ quark pair the analogous of relation 2.1 is now a pair of equations:

$$\beta_{u_1} + \beta_{u_2} + \beta_d = -\beta_{\bar{u}} \tag{3.1}$$
$$\beta_{\bar{u}_1} + \beta_{\bar{u}_2} + \beta_{\bar{d}} = -\beta_u \,, \tag{3.2}$$

where the two gauge parameters on the r.h.s. are not independent. These degrees of freedom are therefore reduced or increased always in pairs. The lowest critical energy is obtained with just one pairing, a configuration that can only occur through a creation of a virtual quark pair, of which only one quark couples with an incident hadron, while the other remains uncoupled. The process is illustrated in figure 6. The energy at which this is expected to occur is obtained as $0.942\ [= \text{m}_p + m_{u,d}]\,\text{GeV} \times 137 \times \mathcal{O}\left(\left[(\log_{10}[(\sqrt{m_p/m_\pi}) = 2,6] = 0.42) + 19\right] / [22]\right) [= 120.9] + 0.942\,\text{GeV} \approx 114,8\,\text{GeV}$. If in the calculation of the average mass scale the proton mass weights more than what assumed in this computation,

[8]The variation with time is at present small enough to be neglected for practical purposes: for what matters the physics of particle accelerators, it can safely be considered constant. The variation of scales is only relevant at cosmological level, where its effects are not at all negligible (see section 7 of Ref. [3] and Ref. [12]).

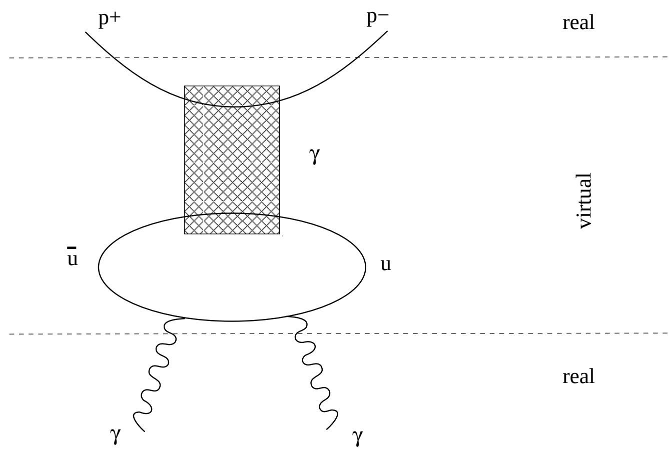

Figure 6: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual $u\bar{u}$ pair creation at the pion-like critical energy.

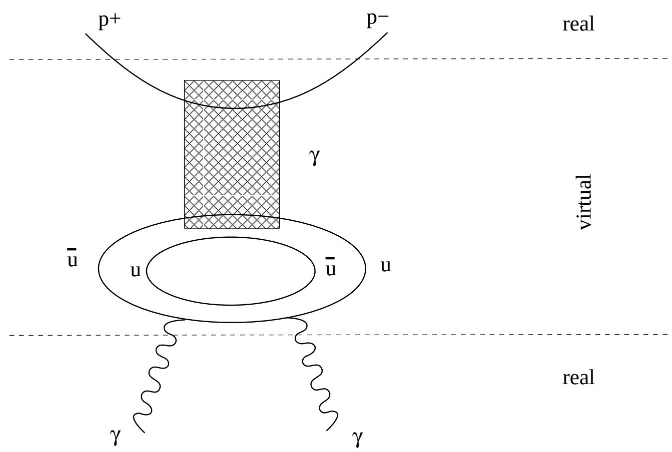

Figure 7: Representation of a $p\bar{p} \to \gamma\gamma$ scattering channel via virtual $\pi\bar{\pi}$ pair creation at the pion-like critical energy.

one obtains a lower critical energy. The uncertainty in this computation due to the approximation implicit in the choice of the energy scale for the renormalization of the electromagnetic coupling is of the order of $2 \pm 3\%$, allowing a range of critical energies between some $\sim 110 - 111$ GeV to some $\sim 115 - 116$ GeV. Notice that we don't need to think that a pair of full pion states is produced. This is an alternative channel, which is illustrated in figure 7. In this second case, an analogous computation, taking as starting point the mass of the proton plus the mass of the pion ($\sim 129\,\mathrm{MeV}$), gives an enhancement of the cross section at around 130 GeV. A peak at a slightly higher energy is obtained when the virtual quark pair is of the type $s\bar{s}$ (K-like state). In this case, inserting the strange quark mass ($\sim 100\,\mathrm{MeV}$) and evaluating the coupling as before, but at an intermediate energy scale between the proton and the K-meson, we obtain $1.043\,\mathrm{GeV} \times 137 \times \mathcal{O}(19.12/22) + 1.043\,\mathrm{GeV} \approx 125\,\mathrm{GeV}$. This concurs to increase the strength of the enhancement around 125 GeV. Considering instead as evaluation scale for the electromagnetic coupling an analogous average scale, but this time with the average taken between the proton mass and the mass of the bare s-quark, one obtains a peak close to 130 GeV. If one further takes into account the possibility of virtually producing not only the $s\bar{s}$ quark pair, but a whole K-meson pair, one gets a peak at an energy about 50% higher than these energy scales. Along the same line, one can compute the critical energies for the enhancements occurring at a higher scale, produced by $c\bar{c}$, $b\bar{b}$ and $t\bar{t}$. They are expected to show up respectively at $\approx 266\,\mathrm{GeV}\,[p-c]$, $\approx 594\,\mathrm{GeV}\,[p-b]$ and $\approx 1,8 \times 10^4\,\mathrm{GeV}\,[p-c]$ [9]. In the case of strong coupling among quarks of the colliding hadrons, the quark on the r.h.s. of 3.2 forcedly coincides with one of those on the l.h.s. of 3.2. The two equations are therefore always coupled and the situation is equivalent to a double pairing, leading to a α^{-2} volume enhancement factor, at a much higher critical energy [10].

No enhancement of this type is expected to occur when the virtual pair produced in the scattering consists of charged pions: In the case of $p\bar{p}$ scattering the quarks of the virtual pions re-combine with those of the proton and anti-proton to give rise once again to pions, produced through a rearrangement of the degrees of freedom; in the case of lepton-antilepton scattering, there is no possibility of forming pairs with the quarks of the pions which, at the strong coupling, can lead to a reduction of the electromagnetic gauge symmetry. This is due to the fact that pions, even charged pions, are made of quark-antiquark pairs (e.g. $\pi^+ \leftrightarrow u\bar{d}$). The $SU(2)$ symmetry relating *up* and *down* in this scenario is broken by the introduction of masses. Since these run as a power of the inverse of the age of the universe, $m \sim 1/\mathcal{T}^p$ for appropriate exponents p, at the present conditions of the universe, i.e. at large age/volume ($\mathcal{T} \gg 1$), it can be considered a kind of "soft breaking". On the contrary, the gauge parameters of the electromagnetic gauge group, and in particular relations like 2.1 involving the breaking into quarks and leptons, are scale-insensitive. As a consequence, for the gauge parameters of the electromagnetic group the separation between families of particles and, inside each family, between $SU(2)$ doublets, are second-order effects: in first approximation the *up* and *down* of each doublet are to be considered the same kind of particle, simply with a different charge. Also a $\bar{d}$ quark is like an anti-u quark, simply with a different normalization of the charge. Since all mesons are of the type $q_i\bar{q}_j$, where i and j run over the families of quarks and the two values indicating the upper and down members of an $SU(2)$ pair, for the sake of the present analysis they can all be considered of the type $q\bar{q}$, i.e. consisting of a quark and its anti-quark. For all of them, the charge neutrality condition analogous to 2.1 is of the type $\frac{1}{3}\beta + \frac{2}{3}\beta = \beta$, with *just one parameter*, as is the case of a lepton-antilepton pair. This implies that already at the weak coupling the set of particles of the pair do transform under $U(1)$ *all together*, as if they were one single particle. The analogous of relation 2.1 does not involve in this case free parameters, and there is no volume group factor to be lost at the strong coupling. For what matters the number of gauge parameters, there is therefore no difference between weak and strong coupling, and we expect no enhancements of the cross section due to meson-lepton bound states to occur.

To summarize, there are seveal configurations concurring to enhance the $\gamma\gamma$ decay channels, spread out in an energy interval going from $\sim$ 111 GeV to $\sim$ 130 GeV, with some peaks around 111-115 GeV, 125 GeV, and 130 GeV. Further enhancements are to be found at higher energies. Since in these processes we don't deal with diverging quantities, each channel contributing to this kind of resonance is expected to enhance the decay amplitude by a relatively small amount. Its effect may therefore be difficult to detect and identify out of the ground decay channels and the statistical noise fluctuations, unless there are several peaks close enough to each other, so that their widths can overlap. Around 125 GeV there is indeed a whole bunch of configurations with peaks potentially overlapping due to their statistical width. They must be compared with the resonance found in the $p\bar{p}$ scattering at LHC [4, 5, 6], which has an analogous signature. This is the energy at which this effect is expected to manifest itself in the strongest way. Besides this line, at a lower level of strength we expect to find the line around 130 GeV, which is also the result of a collection of contributions. Although apparently not detected in the Large Hadron Collider, this threshold could be the line observed by astronomers [9, 7, 8, 10], that in our framework is therefore not interpreted as an evidence of Dark Matter. Astrophysical observations give indications also for a line around 111 GeV [11], which could be compatible, within the approximations implied in our computations, with the enhancement at 111-115 GeV we have found as first energy threshold.

[9]In detail: $m_c = 1,29\,\mathrm{GeV} \Rightarrow$ proton-charm $\to (0,938 + 1,29) \times 137 \times \mathcal{O}[19/22] + 2,228 \sim 266\,\mathrm{GeV}$; $m_b = 4,18\,\mathrm{GeV} \Rightarrow$ proton-bottom $\to (0,938 + 4,18) \times 137 \times \mathcal{O}[18,5/22] + 5,118 \sim 594\,\mathrm{GeV}$; $m_t = 173,3\,\mathrm{GeV} \Rightarrow$ proton-top $\to (0,938 + 173,3) \times 137 \times \mathcal{O}(18/22) + 174,238 \sim 19,705 \approx 1,8 \times 10^4\,\mathrm{GeV}$.

[10]For the purpose of determining the scale of the critical energy it is not so relevant to decide if one has to add to the computation the mass of the free virtual quark or the one of the meson (it is a matter of 100 MeV's order till 1-2 GeV as compared to the 100 and more GeV). It matters if it has to be included in the multiplicative rescaling through α^{-1} factors. If we do this in the case of pions we obtain $1,070 \times 137 \times (19/22) + 1,070 \approx 128$, a contribution which is going to increase, and widen out, the peak around 130 GeV.

4 Conclusions

In this work we have discussed enhancements of the cross section of the particle-antiparticle electromagnetic interaction, that are not predicted in quantum field theory. They may result in resonance lines in the spectrum of the photons produced in particle colliders, or in the cosmic radiation detected by telescopes.

We have performed our investigation within the theoretical framework proposed and discussed in Refs. [1, 2, 3], which is characterized by the complete absence of freely adjustable parameters. Our proposal therefore is not based on modifications applied to known models, involving fine-tuning of parameters, and some data-fitting, but explores the implications already contained in the formulation given in Refs. [1, 2, 3]. In this theoretical framework, amplitudes are determined by the combinatorial possibilities of distributing along space a certain amount of energy, which end up forming the geometry of the region in which the physical phenomenon under consideration takes place. Elementary degrees of freedom such as free elementary particles, and their propagation and interaction, are just a way of parametrizing this "bunch of evolving geometries".

In a scattering of electrically charged particles, for certain values of the center-of-mass energy the geometry, and therefore physics, is equivalent to a situation of effective strong coupling of part of the (electromagnetic) interaction. This leads to a larger weight in the phase space, and therefore to an enhancement of the scattering amplitude. This is due to the increased number of possible decay channels at these particular energy thresholds. The increase in the scattering amplitude is of order of magnitude comparable to the main process. In certain regions of the energy spectrum several thresholds of this kind are so close to each other to almost staple together, resulting in a clear experimentally detectable rise of the scattering amplitude, that shows up like a resonance. We account in this way for the 125 GeV resonance detected at LHC, usually interpreted as a Higgs signal, and for other two lines in the photon spectrum, detected by analyzing cosmic radiation collected by telescopes (Fermi-LAT), at ~ 111 GeV and ~ 130 GeV. In our case, there are no new particles at play, neither the Higgs for the 125 GeV resonance at LHC, nor Dark Matter in whatever form for the other two lines, but aspects of already known interactions which are not accounted for by quantum field theory. The strength of our approach relies in the fact that, owing to the absence of freely adjustable parameters, the entire theoretical scenario is a kind of highly predictive rigid block. It is therefore a rather non trivial fact that within this scenario one can compute physical quantities and find results in agreement with the experimental measurements in many aspects of physics: from the spectrum and the masses of elementary particles to their interactions and their strength, to several cosmological parameters (see Ref. [3]), as well as the CP violation parameters, correctly predicted also for the D-mesons system [13]; in the physics of high-temperature superconductors [14], or even in some aspects of the natural evolution [12]. Together with the analysis presented in this paper, these facts should perhaps suggest a different attitude toward the explanation of experimental results. Maybe we are at the point where "new physics" should no more be intended as "new degrees of freedom within an old theoretical approach", but as "new theoretical approach" to already known degrees of freedom.

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