

## NOVEL IDEAS ABOUT EMERGENT VACUA

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Arguments for special *emergent vacua* which generate fermion and weak boson masses are outlined. Limitations and consequences of the concept are discussed. If confirmed, the Australian dipole would give strong support to such a picture. Preliminary support from recent DZero and CDF data is discussed and predictions for LHC are presented.

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## 1. General introduction

The *hierarchy problem* in particle physics is used as a guidance to find theories beyond standard model [1]. The argumentation in some way wrongly presumes a separation of particle physics and cosmology. Without such a separation there is no need to directly connect masses to Planck scale physics as a manageable scale is available from the cosmological constant, more or less corresponding to the neutrino mass scale. As in Planck scale based models the spread in the fermion mass scales will have to be explained. This is considerably easier in a two-scale model in which combinations of the GUT scale and dark energy scale can appear.

This argument seems just to change the context as cosmology contains a worse scale problem [2]: It is widely assumed that the cosmological constant corresponds to the vacuum energy density caused by a condensate [3, 4]. The properties of the condensate have then somehow to reflect a Grand Unification Theory (GUT) scale of the interactions when it presumably was formed (*i.e.* about  $10^{15}$  GeV), whereas the flatness of the universe requires a non-vanishing but tiny cosmological constant (of about 3 MeV) [5].

The size of this gap rises a serious question. It is not excluded that a dynamical solution of a type envisioned for the hierarchy problem of particle physics [6, 7] will eventually be found to be applicable. The opposite opinion

seems more plausible. It considers it impossible to create such scales factors in a direct dynamical way: A Lagrangian with GUT scale mass terms cannot contain minima in its effective potential involving such tiny scales. Of course, condensates do contain compensating energy terms, but without a new scale true field theoretical minima have to stay close to the GUT or Planck scale or they have to vanish.

Besides this plausibility argument there is a formal problem with the conventional view. The term hierarchy problem is properly used if from a single available scale derived scales have to be obtained which are non-vanishing but many orders of magnitude away. The discussed cosmological problem is not a hierarchy problem. Other scales like the age of the universe are available which can bridge the scale gap.

The observed tiny non-vanishing cosmological constant can just mean that given the age of the universe the true minimal vanishing vacuum state is not reached<sup>1</sup>. Our physical vacuum is then defined as an effective ground state. The spontaneous symmetry breaking has to be replaced by an evolving process yielding an unfinished vacuum structure. Its tiny mass density indicates that the present condensate has to be quite close to a final one. As vacuum-like state the condensate has to largely decouple from the visible world.

What could be the history of such a physical vacuum state? It is formed at a condensate- (*e.g.* technicolor) force mass scale, which is assumed to more or less coincide with the GUT scale taken to be somehow directly connected to the Planck mass. In a chaotic initial phase bound composite states are formed with considerable statistical fluctuations. As the mass scale and the potential scale are of the same order, these states can sometimes be more or less massless on a GUT scale. Their initial GUT scale geometric extend is not fixed dynamically by a mass scale. They or their configurations can reduce their remaining energy by geometrical extending. In this evolving process they more and more decouple from the localized hotter incoherent rest. This decoupling works only in one way. At their scale they can, of course, radiate off energy eventually absorbed by the much hotter rest. As a result of cooling down eventually a quantum vacuum is formed in a quantum mechanical condensation<sup>2</sup>. Its properties have to be constant, perhaps almost over GLyr distances [14]. The assumption is that it reaches coherence over a large, say

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<sup>1</sup> Studying the cosmological evolution similar ideas involving a time-dependent vacuum state [8,9,10] were considered. However, based on the scale argument we here stick to the hypothesis that the energy density of the true minimal state vanishes without time dependence. An undisturbed vanishing vacuum energy also determining the structure of the space was postulated in a less phenomenological paper by [11,12,13]. Their basic premises exactly correspond in this point to the discussed concept.

<sup>2</sup> Such a quantum mechanical condensation is reasonable. It is presumably actually observed in the superfluid center of cold neutron stars.

galactic, scale. As explained below a lower limit of this coherency scale can be obtained from weak interactions. Eventually, if the universe continues to expand it will, of course, reach a vanishing energy density<sup>3</sup>.

The advantage of this picture is that it requires no new scale. States without scale are known from condensed matter physics and they are called “gap-less” [11]. Without such an extra scale the evolution of the dark energy in a comoving cell  $\epsilon_{\text{vac.}}$  has to be a linear decrease such as

$$\frac{\partial \epsilon_{\text{vac.}}}{\partial (\epsilon_{\text{vac.}} t)} = -\kappa \epsilon_{\text{vac.}},$$

where  $\kappa$  is a dimensionless decay constant and  $t$  time. The absence of the usual exponential decrease has the consequence that the age of the universe is no longer practically decoupling and irrelevant.

The expansion of the universe is not linear in time and in the above equation the time  $t$  has presumably to be replaced by the dynamical relevant expansion parameter  $a$  to obtain a less rough estimate. It yields  $\epsilon_{\text{vac.}} \propto \frac{1}{a}$ . Phenomenologically the expansion constant is initially taken to be  $a \sim \sqrt{t}$  and later on  $a \sim t^{2/3}$  [5]. The “hierarchy ratio” of grand unification scale and present vacuum scale

$$\frac{\epsilon_{\text{GUT}}}{\epsilon_{\text{vacuum}}(t_0)} = 10^{27}$$

can be obtained from the age of universe

$$t_0 = 5 \times 10^{46} \frac{1}{M_{\text{GUT}}}$$

with  $a \propto t_0^{0.5}$  resp.  $0.66$  to be

$$\frac{\epsilon_{\text{GUT}}}{\epsilon_{\text{vacuum}}(t_0)} = 2.2 \times 10^{23} \text{ resp. } 1.4 \times 10^{31}.$$

To the accuracy considered, the problematic hierarchy ratio is explained.

For the emergent vacuum reached in this way a rich and complicated structure is natural. Heavier masses might involve combined scales. As suggested by Zeldovich, Bjorken and others [16, 17] combinations of suitable powers of both scales

$$H M_{\text{Planck}}^2 \sim \Lambda_{\text{QCD}}^3$$

might explain needed intermediate mass values. The Hubble constant  $H$  is here related to the condensate mass density and  $\Lambda_{\text{QCD}}$  is the QCD mass

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<sup>3</sup> Also the Casimir contribution to the dark energy vanishes in this limit [15].

scale. In chiral perturbation theory the mass of the pion-like GUT-scale bound state can be estimated as [18]

$$\begin{aligned} M^2 &= B_{\text{condensate scale}} \times (\text{fermion mass scale}) \\ &= (3 \text{ MeV} \times 10^{16} \text{ GeV})^{\frac{1}{2}} = 170 \text{ GeV}. \end{aligned}$$

All observed masses lie between the dark energy scale and this Goldstone state scale.

The above hierarchy argument is not new [13, 19]. Of course, the argumentation presented is rather vague. However, without the constraint that the physical vacuum is at an actual minimum, there is too much freedom and it seems futile to try to obtain a more definite description. A realistic *ab initio* description is presumably impossible. Actually this lack is quite typical for most condensed matter in the solid state physics where the term Emergent Phenomena was coined for such objects [20, 21]<sup>4</sup>.

Sometimes “emergent vacuum” is used as a synonym with the “consecutively broken vacuum” of the standard model [24]. Here we take a narrower definition sometimes called strong emergence [20, 25] which includes basic unpredictability. The established complexity of the known part of the vacuum legitimates this assumption. It has two immediate consequences:

- (i) It is extremely ugly from a model building point of view and actually leads to a murky situation: *The vacuum is largely unpredictable but predictions are necessary for the way science proceeds.* In this way, strong emergency is a physical basis of Smolin’s wall [26] possibly severely limiting the knowledge obtainable.

To proceed beyond this barrier is at least difficult. Quimby and Morales [27] assume an equilibrium and use the zero temperature limit of a thermal field theory. Volovik and Klinkhamer [12, 13] try to rely on analogies to solid state physics. Bjorken argues [17] that the situation is somewhat analogous to the time around 1960 where one had to turn to effective theories to parameterize the data. Here we will not attempt to contribute to this difficult problem.

The rich structure of the (strong) emergent vacuum has a second consequence:

- (ii) The standard model contains many aspects with broken symmetries, asymmetric situations and partially valid conservation laws. In emergent vacuum picture many of these observations might not be truly fundamental and just reflect asymmetries of the accidental vacuum structure. This takes away the fundament of many theoretical considerations. Textbooks have to be worded more carefully.

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<sup>4</sup> As in *geography* many properties of this *Cosmographic Vacuum* [22] are dependent on a chaotic history and seemingly accidental. The name of Cosmography was first used by Weinberg [23].

The second consequence of the emergent vacuum will be expanded here. Physics was often based on esthetic concepts. In this spirit we postulate: “Fundamental physics should be as simple as achievable”. With this postulate it is then possible to come to a number of interesting consistency checks and testable consequences. The basic ignorance of the vacuum keeps such predictions on a qualitative level. Formulated in Bjorken’s historic context today might be a time where simple minded, Zweig-rule type phenomenological arguments [28] are needed to sort things out.

Section 2 will discuss general implications. Aspects connected with fermion and boson masses follow in Secs. 3 and 4. Section 5 turns to indications from Fermilab and predictions for LHC.

## 2. General consequences of emergent vacua

One immediate outcome of this argument is the following cosmological argument. Here no novelty is claimed and on the considered conceptual level it is contained *i.e.* in dark fluid models [29]. In our context it is important as it invalidates an argument for unneeded new particles.

As the present vacuum is not at a unique point it has to be *influenceable by gravity*<sup>5</sup>. The distinction between compressed dark energy and dark matter is blurred. Following the simplicity postulate we assume that a suitable compressibility can eliminate the need of dark matter altogether and lead to an effective MoND description [30, 31, 32]. The changed power dependence predicted from the MoND theory for galactic distances can be obtained if the extra compression-mass density of the condensate drops off in the relevant region accordingly. There is no fine tuning: All mass densities are more or less on the same order of magnitude. Lorentz-invariance is no problem as the resulting effective theory does not touch fundamental laws. We will see later how an almost massless condensate mimics an effective relativistic invariance in the world outside the condensate. The offset between the centers of baryonic and dark matter component, seen after galaxy collisions [33], was said to contradict MoND theory. Here it constitutes no problem as it takes cosmic times to rearrange the dark energy effects.

Another important simple outcome is the fact that not unique vacuum can act as a *reservoir*. It can have several consequences. We begin with the most drastic one, which would eliminate one of the most ugly aspects in physics text books.

It is unsatisfactory and potentially problematic to attribute the matter–antimatter asymmetry to the initial condition of the universe. It is also widely agreed [34] that no suitable, sufficiently strong asymmetry generat-

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<sup>5</sup> The compressibility is here an effect of present day vacuum far away from the Planck scale. We differ from Volovich *et al.*’s model [13] in this point. His condensate stays on a Planck scale but decouples from gravitons.

ing process could be identified. The emergent vacuum offers a simple way to abolish the asymmetry: the vacuum can just contain the matching anti-matter. The vacuum must be charge-less and spin-less, but nothing forbids it to contain a non-vanishing antifermionic density<sup>6</sup>.

Such an antifermionic density could be important for the stability of the vacuum. Most known physical condensates are fermionic. As these extremely extended antifermionic states are practically massless their Fermi repulsion will dominate. They provide an anti-gravitating contribution in the cosmological expansion<sup>7</sup> possibly replacing inflatons. Such a so-called “self-sustained” vacuum was postulated by Volovik [13]. He assumes a filling with superfluid  ${}^3\text{He}-A$  like atoms. Keeping the GUT scale condensation force generic, the condensate can be partially characterized by its color and flavor structure. We here assume that there is no asymmetry in the leptonic sector and that an antifermionic component in the hadronic sector suffices. There are of course many possible contributions. In the following, we consider spin- and charge-less Cooper pairs of antineutron like states.

We follow Bjorken who argues that the various components of the vacuum should not be considered as separate objects [17]. Our picture is that the antibaryonic condensate, whose density is regulated by Fermi repulsion, is accompanied by a somewhat less tidily bound mesonic cloud largely responsible for the fermion masses. Both are then seed to the known gluonic component mimicking the spontaneous chiral symmetry breaking. Are there problems with such a picture?

For such a vacuum structure there is a firm limit on the dielectric constant

$$\frac{\epsilon(\text{vacuum})}{\epsilon_0} - 1 \approx \theta_C^2 < 10^{18}$$

from the unobserved vacuum Cherenkov radiation [37]. However, the considered vacuum state is not excluded. Its density is well known. As we will see later the mesonic and the antibaryonic densities in such a vacuum have to be of the same order of magnitude. The antibaryonic density equals the baryon density outside the vacuum which is

$$\begin{aligned} n_{\text{baryon}} &= \rho_c \times \Omega_{\text{baryon}} / m_{\text{neutron}} \\ &= 0.25 \times \text{m}^{-3} = 1.9 \times 10^{-39} \left( \frac{\text{MeV}}{\hbar c} \right)^3. \end{aligned}$$

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<sup>6</sup> A recently proposed model of Hylogenesis [35] assumes that the compensating anti-matter sits in the dark matter part of the vacuum, here not accepted as something separate. The Greek word means genesis of wood. It is used in philosophical texts as general building material.

<sup>7</sup> Models in which the pressure in the cosmological equation is a function of the density were considered in [36].

The spin-less GUT scale bound states in the considered vacuum have no initial dipol moments. A factor  $(10^{18} \text{ MeV}/\hbar c)^{-3}$  has to be added to obtain the dielectric constant. The result is well below the limit.

The simplicity postulate presumably requires grand unification. In a framework in which fermions represent a  $SU(5)$ ,  $SO(10)$  or a similar gauge group, proton decay-like processes could present a problem for the antibaryonic vacuum. Depending on the details of the symmetry breaking and on evolution of temperature and fermion masses processes like

$$\bar{d}_{\text{right}} \bar{d}_{\text{right}} \rightarrow d_{\text{left}} \nu$$

could occur without the protection of large mass scale differences possibly destroying the condensate.

Presumably one can find a symmetry breaking and evolution path which avoids the problem. A more drastic solution is the following: In the emergent-vacuum framework left- and right-handed GUT partners do not have to correspond to the mass partners<sup>8</sup>. Most decay channels of the antineutron-like states are then excluded. Two remaining channels involve a charged lepton and a strange quark. It can be prevented by zeroes in the corresponding lepton–quark Cabibbo–Kobayashi–Maskawa matrix. The evolution of the vacuum could naturally select such a stable vacuum configuration. It would also explain the observed stability of the proton.

It is non-trivial to obtain a sufficiently uniform vacuum state. By themselves the vacuum states are extremely extended. Initial statistical fluctuation could be augmented by magnetic effects in a rapidly expanding universe [38] separating different  $U(1)$ -charges at least for a time relevant for condensation. Known condensation often involves replication processes which select certain species and allow to amplify initial asymmetries over many decades. Once an asymmetry between vacuum and visible world is

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<sup>8</sup> The condensate binding would have to be generation dependent and in analogy to the deuteron binding mixed generation components could be required in the condensate (leaving the  $nn$ - or  $pp$ -state unstable). As an example we take  $SO(13) \rightarrow SO(10) \times SO(3)$  where the symmetry breaking is assumed to involve  $SU(5)$  and where the generational  $SO(3)$  contains only color triplets for fermion and gauge bosons. Fermi-statistics requires identical spin and isospin symmetry. For the antineutron decay two  $\bar{d}_L$  have to decay in a  $q_R$  and a lepton. As the right-handed mass partner of the  $\bar{d}_L$  quarks will be in a different  $SO(10)$  generation the produced quark will have a second or third generation mass. Decays involving neutrinos are then kinematically not possible. Of course, decays involving charged leptons and strange quarks could be possible. However they might have to involve  $\tau$  leptons as the corresponding Cabibbo–Kobayashi–Maskawa matrix is unknown. The required exact zero entries seem unnatural. However, the evolution can select stable vacuum and adjust the corresponding mass matrix in a dynamical process. In this framework the proton decay involves the same  $\tau$  lepton.

established, annihilation processes within the vacuum radiating into the visible world should purify its antimatter nature. The GUT scale condensation is thought to precede at least part of an inflationary period. In this way a relatively small area can be magnified to extend over essentially our complete horizon [39].

There is, however, no reason that the tiny region, we have originated from, happens to have a constant (*i.e.* extremal) fermionic density. In Section 4 we will discuss how a higher antifermionic density increases the vector-boson mass. So we expect a temporal and spatial variation of masses. As long as all masses vary in the same way, it will be hard to observe.

The fine structure constant is not fundamental [14, 40]. This holds in any framework with a non-fundamental vacuum structure. The fine structure constant is determined by  $1/e^2 = 1/g^2 + 1/g'^2$  at the vector-boson mass scale and relates the fine structure constant to the, in this context, fundamental U(1) and SU(2) couplings. As the renormalization scale dependence of the left-hand and right-hand side is different, the fine structure constant will depend on point where the relation can be applied, *i.e.* on the non-fundamental  $Z_0$  mass. The fine structure constant decreases with increasing  $M_{Z_0}$ .

As the fine structure constant enters, different optical spectral lines with distinct powers astronomical measurements in far away galaxies are possible with high precision. There is evidence for a spatial dependence of the form

$$\frac{\Delta\alpha}{\alpha} \sim B \cos(\Theta) + m,$$

where  $B = 1.1 \pm 0.8 \times 10^{-6} \text{ GLyr}^{-1}$ ,  $m = -1.9 \pm 0.8 \times 10^{-6}$ , and  $\Theta$  is an angle to a specified sidereal direction [14]. If confirmed, this means that the expected spatial variation has a GLyr scale. Naturally the antifermionic density and the vector-boson mass was higher in the past, explaining the observed reduction in the fine structure constant at  $90^\circ$ . The same sign in the variation of the fine structure constant with time was indicated by the LNE-SYRTE clock assemble preliminary yielding

$$\frac{\partial}{\partial t} \alpha / \alpha = -0.18 \pm 0.23 (10^{16} \text{ year})^{-1}$$

involving a different time period [41].

The antimatter vacuum was introduced for reasons given above. It also affects other symmetries. Whether the resulting consequences are consistent offers a non trivial cross check.

### 3. Vacuum and fermion mass matrix

How do fermions interact with the vacuum? As said, the tiny energy scale of the vacuum requires a huge geometrical extension. Hence all momenta exchanged with the vacuum have to be practically zero. Such interactions are described with scalar, first order terms of a low energy effective theory [18]. Scalar interaction with the (very light) vacuum state does not depend on its Lorentz system. There is no contradiction to the observed *Lorentz invariance* in the outside world [42].

All masses have to arise from interaction with the vacuum. Their effective couplings should be rather similar. The mass differences have to originate in distinct densities of the components of the vacuum they couple to. The excessive number of mass parameters is unacceptable for fundamental physics. Here the problem is solved by attributing them to properties of the emergent vacuum. The concept then conforms to Hawking’s postulate [43], stating that “the various *mass matrices cannot be determined from first principles*”. The postulate does not preclude that certain regularities might be identified and eventually explained [44, 45].

We denote vacuum-fermions with a subscript (V). The relevant interaction  $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$  in the lowest perturbative order is shown in Fig. 1. Relying on the Fierz transformation it can be shown to contain a scalar exchange. In a theory without elementary scalar particles this flavor exchange term is the only such contribution.

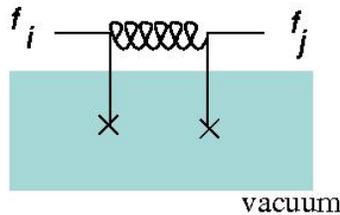


Fig. 1. A process responsible for the fermion mass terms.

We assume that such a flavor-dependent contribution stays important if higher orders in the perturbative expansion are included. The matrix elements then depend on the corresponding fermion densities and on the properties of their binding, as interactions with fermions involve replacement processes [27, 46]. Multi-quark baryonic states should be more strongly bound than the mesonic states [47] and fermion masses should be dominated by the less tidily bound mesonic contribution. In this way, the required dominance of the mesonic  $t\bar{t}$  contribution is not diluted by the light antiquarks from the antineutrons.

The *flavor half-conservation* is a serious problem in the conventional view. Here, the flavor of  $q_i$  does not have to equal the flavor of  $q_j$ . In this way flavor conservation can be restored and the apparent flavor changes in the visible world can be attributed to a reservoir effect of the vacuum. As the vacuum has to stay electrically neutral, the mass matrix decomposes in four  $3 \times 3$  matrices which can be diagonalized and the CKM matrix can be obtained in the usual way. If the coherent vacuum state is properly included unitarity relations are not affected. As the matrix elements mainly depend on fermion densities and not on messenger particles with intermediate mass scales no significant scale dependence is expected. In this way flavor changing neutral currents are suppressed on a tree level. As in the standard model, non tree level corrections from weak vector mesons or heavier bosons are tiny.

The antifermionic vacuum state is obviously not symmetric under CP and CPT symmetry. This allows to restore these symmetries for fundamental physics. Without any assumptions about discrete symmetries it is then easy to see why CPT is conserved separately in the outside world and why CP is not.

In the low momentum limit the interaction  $f_i + (\bar{f}_i)_V \rightarrow f_j + (\bar{f}_j)_V$  will equal  $\bar{f}_j + (f_j)_V \rightarrow \bar{f}_i + (f_i)_V$  by continuity in the exchanged momentum. In consequence, the asymmetry of the vacuum cannot be seen and CPT is separately conserved in the outside world.

On the other hand, the  $(\bar{q}_i)_V/(q_i)_V$  asymmetry in the vacuum will differentiate between  $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$  and  $\bar{q}_i + (q_i)_V \rightarrow \bar{q}_j + (q_j)_V$ . In consequence CP appears as not conserved<sup>9</sup>.

#### 4. Vacuum and vector-boson masses

How do weak vector bosons obtain their masses? Relevant is a Compton scattering process like  $W_\mu + (\{\bar{q} \cdots\}_i)_V \rightarrow W_\nu + (\{\bar{q} \cdots\}_j)_V$  shown in Fig. 2.

In this framework pure gluon and meson condensates (*i.e.* simple Technicolor [48] models with GUT binding scale) have a problem. In the low momentum limit the interaction with the  $B$ -meson measures the squared charges of the vacuum content. As these objects are  $U(1)_B$  neutral states they cannot contribute to a  $m_B$ -mass term. The appearance of antibaryonic states in the vacuum provides a  $U(1)_B$  charge. This has to be considered as an independent success of the antifermionic vacuum concept.

<sup>9</sup> Consider the  $(K_0, \bar{K}_0)$  system as an example. We assume that such a pair was produced and that the  $\bar{K}_0$  remnant is observed in the  $(K_0^L, K_0^S)$  interference region. As postulated above there are more  $\bar{d}$  anti-quarks than  $d$  quarks in the vacuum. The amplitude, in which a pair of  $d$  quarks is effectively deposited in the vacuum during a  $K_0 \rightarrow \bar{K}_0$  transition and then taken back later on during two  $\bar{K}_0$  decays, obtains a different phase as that of conjugate case of a pair of  $\bar{d}$  anti-quarks deposited for the corresponding time. This changing phase exactly corresponds to what is experimentally observed in CP violation.



Fig. 2. A process responsible for the vector-boson mass terms.

Depending on the isospin structure of the bound states in the vacuum the  $m_W$ -mass term can obtain contributions from the mesonic and antifermionic component. It creates a  $(B, W_0)$  mass matrix, which diagonalizes in the usual way. The symmetry of this matrix allows diagonalization and the electrical neutrality of the vacuum ensures  $m_\gamma = 0$ .

One obvious question is why the running Weinberg angle obtained from the running fundamental charges  $g'$  and  $g$  equals a diagonalization angle of the mass matrix. The question is related to the origin of Gell-Mann–Nishijima relation  $Q = T_3 + \frac{1}{2}Y$ . Here, the diagonalization angle has to take a value for which the antineutrons of the vacuum are neutral at the symmetry breaking scale.

### 5. Predictions for LHC

Can one make predictions for LHC? Three “vacuum” fluctuations in bosonic densities are of course needed for the third component of the weak vector bosons. The forces controlling these fluctuations must allow for charge transfers analogously to pion fields in nuclei. Their contribution will lead to an effective scalar interaction with their longitudinal part shown in Fig. 3 manufacturing the mass and adding the third component [49].



Fig. 3. Mixing with the effective scalar.

The rich flavor structure of the vacuum allows to excite many different oscillation modes. Such phononic excitations  $H_{f_i \bar{f}_j}$  directly couple to matching  $f_i \bar{f}_j$  pairs. Of course, three boson couplings like  $WWH_{f_i \bar{f}_j}$  can also appear. Their masses should correspond within orders of magnitude to the weak vector-boson masses.

Unlike GUT-scale bound objects their masses have to somehow reflect the tumbled down vacuum scale. As described above with GUT-scale constituent masses and with the tumbled down physical condensate mass such pion-like states could reach the TeV range.

It is not difficult to distinguish such phonons from the usual Higgs bosons [50] as they couple to the fermions in a specific way. In literature they are called “private Higgs” particles [51], which couple predominantly to one fermion pair.

Their respective masses could reflect the constituents they are made of. The light lepton and light quark phonons then have the lowest mass. The signal of a  $H_{\nu\bar{\nu}}$  could be that of an invisible Higgs boson [52]. The absence of abnormal backward scattering in  $e^+e^-$  annihilation at LEP could limit the corresponding leptonic-“Higgs”-boson to  $M(H_{e^+e^-}) > 189$  GeV [53]. Also the large-transverse-momentum jet production at Fermilab could limit the mass of light quark  $H_{q\bar{q}}$  to an energy above 1 TeV [54].

However, the fermionic coupling constants are presumably much too tiny. The couplings to weak bosons and fermions are drawn in Fig. 4. In the limit of vanishing phonon momenta their couplings correspond to the usual fermion mass terms. For heavier phonons this limit might be far away and meaningless. But for light phonons their couplings should depend on mass of the fermions involved similar to the usual Higgs bosons. Then there is no chance to observe the light phonons in fermionic channels. Their couplings to weak bosons is not known. Very light bosons would be rather stable. With masses in the range of weak vector bosons they could appear as quasi fermi-phobic “Higgs” particles.

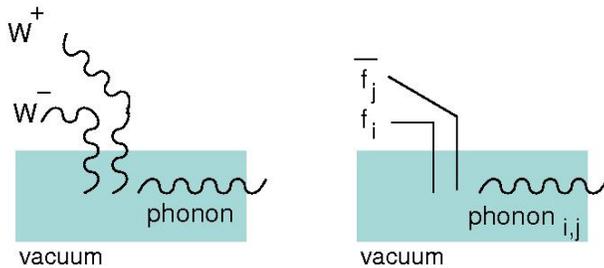


Fig. 4. Coupling to phononic excitations.

For the very heavy quarks there is no problem with the coupling. The  $t\bar{t}$ -phonons will look like a normal Higgs allowing  $t\bar{t}$  decays and will be hard to distinguish. However, the expected mass range is different and such phonons are possibly out of reach kinematically.

The best bet might be the intermediate range. Here, Fermilab collaborations presented two candidates.

The first candidate is a  $\tau\bar{\tau}$ -phonon in a mass range around 360 GeV. It is seen as broad  $\{e^\pm\mu^\mp \text{ missing } p_\perp\}$ -structure in preliminary D0 data [55]. It is said to be statistically on discovery level. At the moment D0 does not trust their  $\mu$ -energy calibration sufficiently to announce it as such.

More significant is the 3.2 sigma excess at 150 GeV in the dijet mass spectrum of  $W$ + jets published by CDF [56]. One of the virtual vector-boson decays  $W^* \rightarrow WH_{s\bar{s}}$ ,  $W^* \rightarrow WH_{c\bar{c}}$  or  $Z^* \rightarrow WH_{c\bar{s}}$  could contribute in the observed region [57] in a way comparable to the seen processes  $W^* \rightarrow WZ$  or  $Z^* \rightarrow WW$  yielding the observed two jet final state.

## 6. Conclusion

The emergent vacuum concept is not a beautiful scenario. If correct, the degree to which theory can be developed is quite limited and one can forget the dream about the *Theory of Everything* at least as far as masses are concerned. However, the presented concept is not unpersuasive and things fit together in a surprising way on a qualitative level. Firmly established private Higgs particles would be an indication that an emergent scenario would be *nature's choice*.

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