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Applications to physics

Beyond Faddeev's interpretation of the Weiberg-Salam interaction model

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Abstract. We provide a mathematical completion of L.Faddeev's hypothesis[1] of the Higgs mechanism without using the Higgs field (Higgs bosons) by using the IQM theory of individual particles. So, we demonstrate mathematically, basing on the IQM gauge theory, that during each interaction of a given massive particle with the bosons (during which this particle changes its energy, momentum and speed), the Goldstone "Mexican hat" potential obtained from particle's Lagrangian density, appears without necessity to introduce the Higgs bosons.

Keywords: Quantum Mechanics, Aharonov-Bohm effect, Massive bosons, Electromagnetism.

[1]Ludwig Faddeev called himself a mathematical physicist whose main interest was in quantum theory. He believed that the aim of mathematical physics is making discoveries in fundamental physics while using mathematical intuition. He saw Mathematical Physics and Theoretical Physics as competitors although he acknowledged that different methods could be used in either discipline. Faddeev was convinced that physics solved all the theoretical problems in chemistry, thus 'closing' that science. He believed that mathematics will create the 'unified theory of everything' and 'close' physics as well, which can be seen as quite a radical opinion. He believed that the more physics uses mathematical methods, the more fundamental this science becomes. He also claimed that there is only one most important unsolved problem in physics: the microscopic description of the structure of matter. He said that physics will be 'finished' for him when the theories of gravitation, relativity and quantum mechanics will be put together into one solid theory.
(From https://mathshistory.st-andrews.ac.uk/Biographies/Faddeev_Ludwig/):

1 Introduction to the Mass Gap Conjecture in Yang-Mills Theory

In early 1954, Chen Ning Yang and Robert Mills [12] extended the concept of gauge theory for abelian groups, e.g. quantum electrodynamics, to nonabelian groups to provide an explanation for strong interactions. The idea was set aside until 1960, when the concept of particles acquiring mass through *symmetry breaking* in massless theories was put forward, initially by Jeffrey Goldstone, Yoichiro Nambu, and Giovanni Jona-Lasinio. The current version of the original Yang-Mills idea is a theory that is known as quantum chromodynamics. This is a model of the fundamental interactions (and therefore all energy in the universe) which proposes that all matter and energy is composed of quarks and their opposites (antiquarks). These interactions are thought to be mediated by the exchange of massless energy bosons called *gluons*. In effect, in physics, *classical* Yang-Mills theory is a generalization of the Maxwell theory of electromagnetism where the chromo-electromagnetic field itself carries charges. As a classical field theory it has solutions which travel at the speed of light so that its quantum version should describe massless particles (gluons).

In order to show these properties of a long-range action of photons, for the electromagnetic field in the vacuum region (where the 4-electric current vector $\mathbf{J} = 0$), expressed by a contravariant 4-potential vector (gauge field),

$\mathbf{A}_4 = (\mathcal{A}_0, \mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3) = (\frac{\phi(t, \overrightarrow{\mathbf{r}})}{c}, \overrightarrow{A}(t, \overrightarrow{\mathbf{r}}))$

where $\mathcal{A}_0 = \frac{\phi}{c}$ and ϕ is a scalar potential and $\overrightarrow{A} = \mathcal{A}_1\mathbf{e}_1 + \mathcal{A}_2\mathbf{e}_2 + \mathcal{A}_3\mathbf{e}_3$ is a 3-dimensional vector potential, such that the electric and magnetic forces in SI system are $\overrightarrow{E} = -\nabla\phi - \frac{\partial\overrightarrow{A}}{\partial t}$ and $\overrightarrow{B} = \nabla \times \overrightarrow{A}$, relatively. So, we obtain the D'Alembert homogeneous equation for each component $\mathcal{A}_j$ of the electromagnetic 4-vector potential gauge field $\Box\mathcal{A}_j \equiv \frac{1}{c^2}\frac{\partial^2\mathcal{A}_j}{\partial t^2} - \triangle\mathcal{A}_j = 0$, whose solution is a wave function which propagates with the speed of light, so that this electromagnetic gauge field is mediated by the *massless* bosons (photons). In 1935 Yukawa [13] found a relation between the mass of the intermediate particle (a boson) and the range of interaction, based on Yukawa potential (used for the strong and weak nuclear forces), $U(r) = -\frac{g^2}{r}\mathrm{e}^{-\frac{r}{L}}$, where for the mass m_0 of this particle, $L = \frac{k}{m_0}$, and g and k are two scaling constants. In the case when the mass is equal to zero (of the photons), $L \mapsto \infty$, this potential becomes the long range Coulomb potential of QED. It is easy to verify that if we change the

D'Alembert homogeneous equation above, by a new term, that is by

$$\Box\mathcal{A}_j \equiv \frac{1}{c^2}\frac{\partial^2\mathcal{A}_j}{\partial t^2} - \triangle\mathcal{A}_j = -\frac{1}{L^2}\mathcal{A}_j \tag{1}$$

we obtain the massive, short distance, solution proportional to $e^{-\frac{r}{L}}$. It is easy to verify that Klein-Gordon quantum equation corresponds to this extended equation (1) with $L = \frac{\hbar}{m_0 c}$ (so called Compton wave length). This equation reduces to D'Alembert homogeneous equation for a massless field $\mathcal{A}_j$ when $m_0 = 0$. In effect, Proca [14] extended the Maxwell equations in QFT to massive spin-1 (vector) bosons (massive photons), by extending the Lagrangian by the massive term $\sum_j \frac{1}{2}\frac{1}{L^2}\mathcal{A}_j\mathcal{A}^j$, in the following *total* Lagrangian density,

$$\mathcal{L} = -\frac{1}{4}F_{kj}F^{kj} - \frac{1}{c}\sum_j \mathcal{J}_j\mathcal{A}_j + \frac{1}{2L^2}\sum_j \mathcal{A}_j\mathcal{A}^j \tag{2}$$

where $F_{kj} = \partial_k\mathcal{A}_j - \partial_j\mathcal{A}_k$ are the components of covariant (and F^{kj} of contravariant) field-strength tensor, and hence $-\frac{1}{4}F_{kj}F^{kj}$ represents the Maxwell Lagrangian (gauge), so that for the source free case, when $\mathcal{J}_j = 0$, we obtain the Proca equation (the Euler-Lagrange equation obtained from the Proca Lagrangian above)

$\Box\mathcal{A}_j \equiv \frac{1}{c^2}\frac{\partial^2\mathcal{A}_j}{\partial t^2} - \triangle\mathcal{A}_j = -\frac{1}{L^2}\mathcal{A}_j + \partial_j\sum_k \partial^k\mathcal{A}_k$,

which in the case when $m_0 = 0$ reduces to the massless Maxwell field in equation. The Proca Lagrangian (2) is not invariant for the gauge transformation because of the presence of the massive term, and by taking the divergence of the Proca equation we obtain that if $m_0 \neq 0$ then $\sum_k \partial^k\mathcal{A}_k = 0$ (the Lorenz gauge field conditions), so that the Proca equation (2) reduces to equation (1) with the massive, short distance, solution proportional to $e^{-\frac{r}{L}}$, as in the case of the Klein-Gordon equation (which is defined for 0-spin particles and not for 1-spin particles as are photons and all other vector bosons).

However, the postulated phenomenon of color confinement in the current Statistical Quantum Mechanics (SQM), where you can only have massive bound states of gauge fields, forming massive particles through their binding energy $E = mc^2$. This is "*mass gap*". This is especially important because the interaction of the gauge fields (called gluons in QCD) and quarks prevent any free gluons/quarks from ever being seen on their own. The evidence that the mass gap in the SQM is real comes from renormalization group calculations of the strength of various interactions; simulations in lattice QCD.

So, Yang-Mills SQM theory proposes the existence of this mass gap in relation to the strong interactions of elementary particles. Classical versions of this theory describe gauge fields with no mass that propagate at the speed of light (see the D'Alembert homogeneous equation above for the electromagnetic gauge field), that is, in such a gauge theory the bosons has to be massless as are the photons in the gauge theory of electromagnetic force. The SQM describes every particle as a certain kind of wave so the mass gap is a major contradiction between the two versions of Yang-Mills theory. One of the most important results obtained for Yang-Mills theory is asymptotic freedom. The relevance of this result is due to the fact that a Yang-Mills theory that describes strong interaction and asymptotic freedom permits proper treatment of experimental results coming from deep inelastic scattering.

Yang-Mills theories met with general acceptance in the physics community after Gerard 't Hooft, in 1972, worked out their renormalization. Renormalizability is obtained even if the gauge bosons described by this theory are massive, as in the electroweak theory, provided the mass is only an "acquired" one, generated by the Higgs mechanism which we will consider in next in the mathematically simpler case of the electromagnetic quantum field theory (QFT).

In particle physics, elementary particles and forces give rise to the world around us. Physicists explain the behaviors of these particles and how they interact using the Standard Model. Initially, when these models were being developed and tested, it seemed that the mathematics behind those models, which were satisfactory in areas already tested, would also forbid elementary particles from having any mass, which showed clearly that these initial models were incomplete. As explained previously, in 1964 three groups of physicists almost simultaneously released papers describing how masses could be given to these particles, using approaches known as symmetry breaking. This approach allowed the particles to obtain a mass, without breaking other parts of particle physics theory that were already believed reasonably correct. This idea became known as the Higgs mechanism.

The simplest theory for how this effect takes place in nature, and the theory that became incorporated into the Standard Model, was that if one or more of a particular kind of "field" (known as a "Higgs field"[2]) happened to permeate

[2]Higgs published the first explanation of his particle in 1964. The "Higgs field" is believed to fill the entire known universe and endows all matter with mass. This "explanation" has been proposed by the team of Englert and Robert Brout, a deceased colleague, who first suggested how elementary particles get their mass by interacting with an invisible field that fills up all of space. Particles that interacts strongly with the "Higgs field" have more mass, and vice versa. But such a hypothesis would generate enormous problems during the creation of our universe [22] by having universe-killing potential. In effect, the rapid inflationary period immediately after the Big Bang nearly 13.7 billion years ago would have thrown our early universe into chaos, the universe would have collapsed as the "Big Crunch".

space, and if it could interact with elementary particles in a particular way, then this would give rise to a Higgs mechanism in nature. In the basic Standard Model there is one field and one related Higgs boson; in some extensions to the Standard Model there are multiple fields and multiple Higgs bosons. This theory is not fully proven also after the famous experiments in CERN, 2012, and still up to this moment there is no according that these experiments really found Higgs bosons instead of other composite particles [34]:

"*Physicists have spotted the Higgs boson performing a new trick, but one that brings us no closer to understanding the workings of fundamental particles... However, despite the work of thousands of researchers around the world, nobody has been able to figure out exactly how it does that or why some particles are more massive than others.*"

In the years since the "Higgs field" and boson were proposed as a way to explain the origins of symmetry breaking, several alternatives have been proposed that suggest how a symmetry breaking mechanism could occur without requiring a Higgs field to exist. Models which do not include a Higgs field or a Higgs boson are known as *Higgsless models*, as Faddeev model considered and completed by the IQM theory in this paper. In these models, strongly interacting dynamics rather than an additional (Higgs) field produce the non-zero vacuum expectation value that breaks electroweak symmetry.

Noted theoretical physicist Stephen Hawking has been convinced that the Higgs boson would not be found, as he had hoped that a more "elegant" mechanism would be found that could explain how particles have mass. It seems that the negation of necessity for the existence of Higgs boson is unpopular in the main stream of physicians.

A number of problems for the existence of Higgs scalar zero-spin bosons and every-present "Higgs field" are addressed in, for example [23]. In effect, the model of strong and electro-weak interactions supplemented by the gravitational interaction and the presence of higher compactified dimensions (Kaluza-Klein, as in my approach), between micro-island particle's metrics, in which all dynamic "Higgs fields" are eliminated, can provide a natural framework for description of elementary particle fundamental interactions as it was supposed for example in [24, 25, 26, 27, 28, 29, 30, 23, 31, 32] but with different ideas. The fact that the compactified extra dimensions can be used for producing the spontaneous symmetry breaking without Higgs boson has been studied in a number of papers (see, for example [33]).

1.1 Higgs Mechanism and Spontaneous Symmetry Breaking

The weak interaction is short-ranged (range around $10^{-15}cm$) and, in the statistical quantum mechanics (SQM), it is explained by the mechanism of the spontaneous symmetry breaking and hence it predicts the *massive bosons* ($W^{\pm}$ and Z). In this case, fermions can exchange three distinct types of force carriers known as the W^{+}, W^{-}, and Z *massive* bosons. In 1968, Sheldon Glashow, Abdus Salam and Steven Weinberg unified the electromagnetic force and the weak interaction by showing them to be two aspects of a single force, now termed the electro-weak force. According to the electro-weak theory, at very high energies, the universe has four field components whose interactions are carried by four massless gauge bosons (each similar to the massless photon). However, at low energies, this gauge symmetry is spontaneously broken down to the $U(1)$ symmetry of electromagnetism. In the SQM theory, this symmetry-breaking would be expected to produce three massless bosons, but instead they become integrated by the other three fields and acquire mass through the Higgs mechanism. These three boson integrations produce the W^{+}, W^{-}, and Z bosons of the weak interaction. The fourth gauge boson is the photon of electromagnetism, and remains massless.

The aspects of gauge symmetries are based on the field transformations $\varphi \mapsto \mathrm{e}^{i\theta}\varphi$ where θ is a constant in the case of global and a function on time-space $\mathbf{r}_4 = (t, \overrightarrow{\mathbf{r}})$ of local symmetries. The complex phase of a field does not appear as a measurable quantities, so that the states described by a different complex phase are physically the same and differ only in mathematical description, so that the global $U(1)$ symmetry, with $\mathrm{e}^{i\theta} \in U(1)$, is a gauge symmetry. There is a well known theorem related to the global symmetry breaking: Goldstone theorem, which tells that every broken generator of a global symmetry group has a corresponding massless Goldstone boson (with spin zero). Let us consider a thin rod with circular cross section, in Fig.1, and apply a force F on the end points of the rod. If the force F is small, nothing happens. However, if F exceeds a critical value F_0, the rod bends in a plane which it chooses at random as shown in Fig.1. The symmetric (unbent) configuration becomes unstable when $F > F_0$, and the new ground state is unsymmetric. Also, there are infinitely many possible new degenerate ground states, which are related by a rotational symmetry. The rod can only, of course, choose one of them, but the others are all reached by a rotation without causing any energy. So we obtained the typical restatement of Goldstone theorem.

Notice that this is valid also when φ is the 3-D wave-packet field $\Psi =$

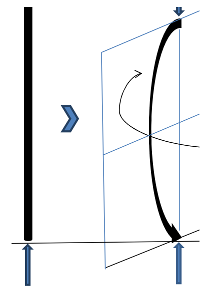

Figure 1: Compressed rod

$e^{-i\varphi_T}\Phi$ of an individual particle (in IQM theory for individual particles [2, 3, 4], complementary to the SQM theory), because the de Broglie pilot-wave phase φ_T is derivable from the particle's real positive distribution function $\Phi(\mathbf{r}_4)$.

Let us consider a simple filed theory example: broken U(1) symmetry. A general Lagrangian for a single complex scalar field φ has the form (in what follows we will use Einstein convention for the sum above the indexes, in order to make simpler the presentation and explanation of the main concepts),

$$\mathcal{L} = \partial_k \varphi \partial^k \overline{\varphi} - V(\varphi\overline{\varphi}) \tag{3}$$

where the first term is the kinetic component of the Lagrangian, invariant under global $U(1)$ transformations, and $V(\varphi\overline{\varphi})$ is the potential invariant under transformation as well. Let us show that V is indeed a potential density component of the Lagrangian density $\mathcal{L} = T - V$, where T is its "kinetic" component. In fact, from the Lagrangian density (3), we obtain the conjugate moments of the complex field φ and $\overline{\varphi}$, $\Pi = \frac{\partial\mathcal{L}}{\partial(\partial_0\varphi)} = \partial_0\overline{\varphi}$, $\overline{\Pi} = \frac{\partial\mathcal{L}}{\partial(\partial_0\overline{\varphi})} = \partial_0\varphi$. So, we can define the Hamiltonian density by $\mathcal{H} = \Pi\partial_0\varphi + \overline{\Pi}\partial_0\overline{\varphi} - \mathcal{L} = T + V$ and hence to verify that $V(\varphi\overline{\varphi})$ is the potential component of this Hamiltonian density. Note that the first (*kinetic*) component of Lagrangian is set in the way that it generates the Klein-Gordon term $\Box\varphi \equiv \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \triangle\varphi$ during derivation of the Euler-Lagrange equation of motion.

So, for $V(\varphi\overline{\varphi}) = (i\mu)^2\varphi\overline{\varphi}$, where $\mu = \frac{1}{L} = \frac{m_0 c}{\hbar}$, we obtain that derived Euler-Lagrange equation of motion is equal to the Klein-Gordon equation for the 0-spin massive particles. Thus, such a kinetic term of the Lagrangian will be present in the whole Higgs theory, by modification only of the potential term $V(\varphi\overline{\varphi})$, so that the Euler-Lagrange equations will be some *kind of modifications* of the "massive" component $(\frac{m_0 c}{\hbar})^2\varphi$ of the Klein-Gordon equation. Let us now

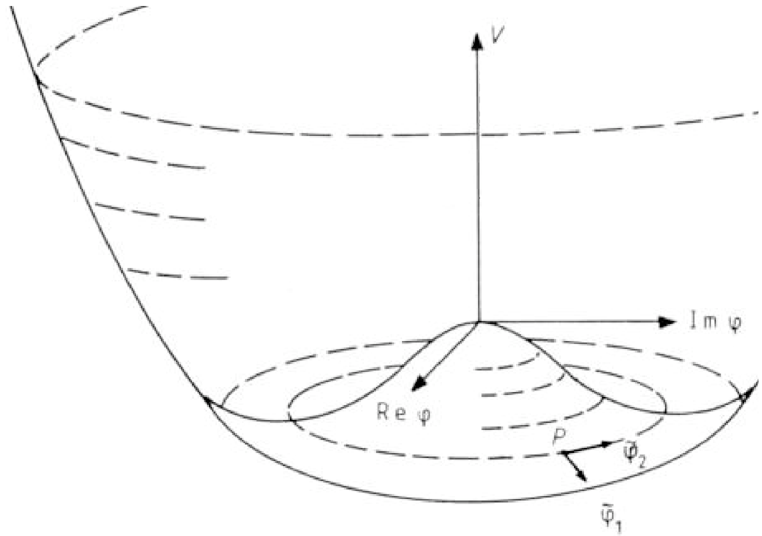

Figure 2: Goldstone 'Mexican hat' potential

consider the potential due to Jeffrey Goldstone [15, 16],

$$V(\varphi\overline{\varphi}) \equiv (i\mu)^2\varphi\overline{\varphi} + \lambda(\varphi\overline{\varphi})^2 = -\mu^2\varphi\overline{\varphi} + \lambda(\varphi\overline{\varphi})^2 \tag{4}$$

where μ and $\lambda > 0$ are real constants, so that the ground state is degenerate as represented by Fig.2, with minimum of V obtained for the φ such that $\varphi\overline{\varphi} = V_0^2 \equiv \frac{\mu^2}{2\lambda}$. The minima of this system are thus degenerate; there are multiple states with the same "vacuum-expectation value" energy $\langle\varphi\rangle_0 = V_0$. The different orientation in the complex plane define different states and we have right to chose one of them as ground state, say $Re(\varphi) = V_0$ and i$Im(\varphi) = 0$, that is, the ground state ket $|0\rangle = V_0 + i \cdot 0$.

The orientation of these states is comparable to the direction of alignment of the spin in the ferromagnet. For the spontaneous symmetry breaking each of the ground state orientations in this complex plane has an equal chance to be the ground state of the physical system (analogously to the direction of the plain defined by the compressed rod in Fig.1), and the ground states are related to each other by the $U(1)$ symmetry of the Lagrangian. For this Goldstone potential, the Lagrangian density (3) is invariant under *global* $U(1)$ symmetry, where Q is the conserved charge for the field φ,

$$\varphi \ \mapsto \ \mathrm{e}^{iQ\theta}\varphi \tag{5}$$

In the SQM field theory, the oscillations around the ground states or 'vacuum' correspond to the real particles. Let us consider now the perturbation,

$$\varphi = (V_0 + \eta(\mathbf{r}_4))\ \mathrm{e}^{i\xi(\mathbf{r}_4)} = \frac{1}{\sqrt{2}}(v + \sqrt{2}\eta(\mathbf{r}_4))\ \mathrm{e}^{i\frac{\varepsilon(\mathbf{r}_4)}{v}} \tag{6}$$

around the ground state, where η and ξ are real functions with, for $v = \sqrt{2}V_0$, $\varepsilon(\mathbf{r}_4) = v\xi(\mathbf{r}_4)$ and $\eta(\mathbf{r}_4)$ two fluctuation fields, such that $\langle\varepsilon\rangle_0 = \langle\eta\rangle_0 = 0$ (so that $\langle\varphi\rangle_0 = \frac{1}{\sqrt{2}}v = V_0$). This perturbation above can be defined as a *local symmetry* $U(1)$ transformation,

$$\varphi(\mathbf{r}_4) \quad \mapsto \quad \varphi(\mathbf{r}_4)\ \mathrm{e}^{\ln[(V_0+\eta(\mathbf{r}_4)/\varphi(\mathbf{r}_4)]+i\xi(\mathbf{r}_4)} \tag{7}$$

so by substitution in (3) we obtain:

$$\mathcal{L} = (\partial_k\eta\partial^k\eta - (4\lambda V_0^2)\eta^2 - (4\lambda V_0)\eta^3 - \lambda\eta^4) + \lambda V_0^4 + (V_0+\eta)^2\partial_k\xi\partial^k\xi$$

There is no mass term for the ξ field, so that this field represents the massless Goldstone boson (by changing ξ, i.e., angular displacement, we do not change the potential V and hence the energy of φ). In fact, a perturbation in the φ_2 direction in Fig.2, i.e., in the angular displacement direction, does not face any resistance since the energy in the adjacent state is the same. Note that the massive term (a quadratic term) in Lagrangian above, $(4\lambda V_0^2)\eta^2$, demonstrate that the filed $\eta(\mathbf{r}_4)$, a perturbation in the φ_1 direction in Fig.2 which changes the potential V and energy of the field φ, is massive with mass $m_\eta = \sqrt{4\lambda V_0^2}$, and hence also φ is massive.

As shown above, in the spontaneous *global* $U(1)$ symmetry breaking, we obtain massless Goldstone bosons. In fact, Goldstone theorem [17] holds only for global symmetry framework. From the general global $U(1)$ transformation (5), it holds that the charge Q is its generator. Although the Lagrangian is invariant under this transformation, the ground state is not invariant under it, and an infinitesimal θ transforms from (5) like

$$|0\rangle \quad \mapsto \quad \mathrm{e}^{iQ\theta}|0\rangle \approx (1 + iQ\theta)|0\rangle \neq |0\rangle$$

and hence, from $Q|0\rangle \neq 0$, Q is the *broken generator* in this global $U(1)$ symmetry. Thus, in this simplest global $U(1)$ case, we have only one broken generator Q, and this corresponds to the massless Goldstone boson (the filed ξ, because global transformation (5) is a particular case of the transformation (7) when $\eta(\mathbf{r}_4) = 0$ and $\xi(\mathbf{r}_4) = Q\theta$.

1.2 Gauge Invariance and Local Symmetries

A key innovation of the 20th century was Herman Weyl's invention of gauge theory, in which a global physical symmetry is replaced by a local one; the arbitrary phase in Hamiltonian-based quantum wave function becomes a function of time-space, a change that requires the existence of the electromagnetic gauge field. Weyl's gauge method, where the global symmetry is transformed into a local one, applied to the Standard-Model symmetry group $SU(3) \times SU(2) \times U(1)$, is enough in the SQM theory to yield the strong, weak and electromagnetic interactions.

It is well known the relativistic invariance or Poincare symmetry and the internal symmetry based on the Lie group $U(1)$ symmetry of phase transformations (the conservation of matter and, dually, of electric charge for Dirac equation). Analogously, we can consider the isospin symmetry $SU(2)$ (used for the electroweak force interactions) and the flavour symmetry $SU(3)$ of the strong force interactions. All of them are continuous *global* symmetry transformations (they give rise to conserved *currents* and *charges* as described by Noether's theorem, that is, they presuppose that, at least in principle, we can measure all the components of a field Ψ at all points $\overrightarrow{\mathbf{r}}$ in space at the same time.

However, here we have to consider the theories which are invariant if the symmetry operations are performed *locally* where the transformation parameters are dependent on local space coordinates (for example, if the rotation angle θ of Lorentz transformation is not constant for all infinitesimal pieces of matter $\Phi_m = \overline{\Psi}\Psi$, but is dependent on its space position $\overrightarrow{\mathbf{r}}$, that is, the rotation angle is a function $\theta(\overrightarrow{\mathbf{r}})$). A gauge theory is a theory where the action is invariant under a continuous group symmetry that *depends on time-space* and such local symmetries introduce these *gauge fields* to the theory which *mediate* a force. Let us consider, for instance, the internal phase transformation, when θ is not a constant phase, but depends on space position $\overrightarrow{\mathbf{r}}$, and when we require that the Lagrangian density $\mathcal{L}$ in equation (22) be invariant under such local smooth changes of phase:

$$\Psi|_{(t,\overrightarrow{\mathbf{r}})} \quad \mapsto \quad \Psi'|_{(t,\overrightarrow{\mathbf{r}})} = \mathrm{e}^{i\theta(\overrightarrow{\mathbf{r}})}\Psi|_{(t,\overrightarrow{\mathbf{r}})} \tag{8}$$

However, since the Lagrangian density $\mathcal{L}$ is invariant under *global* internal symmetry when θ is constant, it is not invariant under local phase transformations given by (8). The problem is that the derivatives of the field Ψ does not transform like the field in (8). In fact we have for $j = 1, 2, 3$ that:

$$\partial_j \Psi|_{(t,\overrightarrow{\mathbf{r}})} \quad \mapsto \quad \partial_j \Psi'|_{(t,\overrightarrow{\mathbf{r}})} = \partial_j[\mathrm{e}^{i\theta(\overrightarrow{\mathbf{r}})}\Psi|_{(t,\overrightarrow{\mathbf{r}})}] = \mathrm{e}^{i\theta(\overrightarrow{\mathbf{r}})}[\partial_j\Psi + i\Psi\partial_j\theta(\overrightarrow{\mathbf{r}})] \tag{9}$$

If we want to consider the phase transformations $\theta(\overrightarrow{\mathbf{r}})$ that differ from a point to point, we have to define *a connection* that specifies the mode how we suppose to transport the phase of Ψ from $\mathbf{r}_4 = (t, \overrightarrow{\mathbf{r}})$ to $\mathbf{r}'_4$ as we travel along some path γ. Let us consider the infinitesimal transport $\mathbf{r}'_4 = \mathbf{r}_4 + \delta\mathbf{r}_4 = \mathbf{r}_4 + \sum_{i=0}^{3} \delta q_i \mathbf{e}_i$, so that with this infinitesimal transport we have the change of Ψ:

$$\delta\Psi|_{\mathbf{r}_4} = \Psi|_{(\mathbf{r}_4+\delta\mathbf{r}_4)} - \Psi|_{\mathbf{r}_4} \tag{10}$$

This problem is analog to the problem of the derivation of a vector field $\mathbf{W}$, with a vector at a point $p = \mathbf{r}_4$, $\mathbf{w}_p = \mathbf{W}(p) = \sum_{j=0}^{3} w_j \mathbf{e}_j$, along a particular curve lying in a given manifold in the differential geometry. In contrast to differential geometry, the vector field Ψ are not vectors in the tangent space (plane) of a manifold, but belong to an "internal" vector space V (like isospin, flavor, etc..) and hence the local transformation (8) can be considered as a time-space dependent change of the basis in V and hence it is a passive transformation.

We require that the physics do not depend on the local choice of the basis, so that the differentiation has to be defined based on the change of Ψ (or $\overline{\Psi}$) relative to the parallel transported Ψ^p, so we have $\delta\Psi|_{\mathbf{r}_4} = \Psi^p|_{\mathbf{r}'_4} - \Psi|_{\mathbf{r}_4}$. In this case we have no Christoffel symbols Γ^j_{ik}, but an imaginary term $-i\alpha\mathcal{A}_k(\mathbf{r}_4)$ where $\mathcal{A}_k(\mathbf{r}_4)$ is a suitably chosen vector field (an element of the Lie algebra belonging to the gauge group element, for example for the unitary group[3], $\mathrm{e}^{i\theta(\mathbf{r}_4)} \in U(\mathbf{r}_4)$) and α is a *coupling constant*. Thus, analogously to the case used for definition of covariant derivative in General Relativity, we have,

$$\delta\Psi|_{\mathbf{r}_4} = (i\alpha\sum_k \mathcal{A}_k(\mathbf{r}_4)dq_k)\Psi|_{\mathbf{r}_4} \ \ \textit{and} \ \ D\Psi|_{\mathbf{r}_4} = \sum_{k=0}^{3}(\partial_k - i\alpha\mathcal{A}_k(\mathbf{r}_4))\Psi|_{\mathbf{r}_4}dq_k \tag{11}$$

with the gauge covariant derivative at point $\mathbf{r}_4$,

$$D_k = \partial_k - i\alpha\mathcal{A}_k(\mathbf{r}_4), \qquad k = 0, 1, 2, 3 \tag{12}$$

(we denote by D'_k the covariant derivative at a point $p = \mathbf{r}'_4$ and $\mathcal{A}'_k$ the k-th component of a 4-vector field

$$\mathbf{A} = (\mathcal{A}_0, \mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3)$$

[3]Historically, while trying to explain the quantum effects of electrodynamics, it was found that Quantum Electrodynamic (QED) could be explained by a $U(1)$ Abelian gauge theory. Yang and Mills then generalized this Abelian $U(1)$ gauge theory to the non Abelian gauge theory case (with the self interactions).

at a point $\mathbf{r}'_4$). From the fact that we want that the Lagrangian density becomes invariant under the covariant derivatives, i.e., $D'_k\Psi|_{\mathbf{r}'_4} = (\partial_k - i\alpha\mathcal{A}'_k)(\mathrm{e}^{i\theta(\mathbf{r}_4)}\Psi|_{\mathbf{r}_4}) = \mathrm{e}^{i\theta(\mathbf{r}_4)}(\partial_k - i\alpha\mathcal{A}_k)\Psi|_{\mathbf{r}_4} = \mathrm{e}^{i\theta(\mathbf{r}_4)}D_k\Psi|_{\mathbf{r}_4}$, we obtain that $\mathcal{A}_k$ should transform like

$$\mathcal{A}_k(\mathbf{r}_4) \quad \mapsto \quad \mathcal{A}'_k(\mathbf{r}'_4) = \mathcal{A}_k(\mathbf{r}_4) + \frac{1}{\alpha}\partial_k\theta(\mathbf{r}_4) \qquad k = 0, 1, 2, 3 \tag{13}$$

Consequently, we conclude that we can promote a global symmetry to local (i.e., gauge) symmetry (for example, from $U(1)$ into $U(\mathbf{r}_4)$) by replacing the standard derivative operators ∂_k by the covariant derivative operators D_k. The standard model of elementary particles, which is based on the concept of local gauge invariance, has shown to be very successful theory. Let us consider a parallel transport at finite distances, for example in the case of the Abelian symmetry group $U(1)$, from the initial point $\mathbf{r}_4$ into the final point $\mathbf{r}'_4$, so that an infinitesimal parallel transport along a finite curve $\gamma(\mathbf{r}_4, \mathbf{r}'_4)$ is given by (11) which formally may be integrated

$$\Psi^p|_{\mathbf{r}'_4} = \mathrm{e}^{i\alpha\int\mathcal{A}_k(z)dz^k}\Psi|_{\mathbf{r}_4} \tag{14}$$

In fact, for infinitesimal transport, by taking the Taylor approximation, we obtain $\Psi^p|_{\mathbf{r}'_4} = \Psi^p|_{(\mathbf{r}_4+\delta\mathbf{r}_4)} \approx (1 + i\alpha\sum_k\mathcal{A}_k(\mathbf{r}_4)dq_k)\Psi|_{\mathbf{r}_4} = \Psi|_{\mathbf{r}_4} + \delta\Psi|_{\mathbf{r}_4}$.
Remark: There is a subset of configurations of material fields Ψ that changes only because of the presence of the gauge field. They are *geodesic* configurations which satisfy the equation $D_k\Psi = 0$ for $k = 0, 1, 2, 3$, which is equivalent to linear equation $\partial_k\Psi = i\alpha\mathcal{A}_k\Psi$.
□

Let as consider now a *local* symmetry framework for $U(1)$ transformation (which introduces the gauge 4-vector potential field $\mathcal{A}_j$ and covariant derivative D_k in the place of partial derivative ∂_k), which has a parameter $\theta(\mathbf{r}_4)$ that depends on time-space, in the gauge theory for the electromagnetism. The gauge boson in this model becomes massive through spontaneous symmetry breaking of the photon. For the stable massless bosons we have the long range electromagnetic force. A situation in which photons are massive is, for example, in a superconductor where $U(1)$ gauge (local) symmetry is spontaneously broken. The Higgs mechanism (in the original case of the non-Abelian gauge theories such as $SU(2) \times U(1)$ gauge symmetry that describes the electroweak interaction, this mechanism allows the $W^{\pm}$ and Z bosons to be massive) explains how a field with an (asymmetric) non-zero ground state can be source of massive gauge bosons. The Lagrangian for the Higgs field Ψ, in the case of electromagnetism, with a $U(1)$ gauge symmetry has the following form [16],

$$\mathcal{L} = -\frac{1}{4}F_{kj}F^{kj} + D_k\Psi\overline{D^k\Psi} - (i\mu)^2\Psi\overline{\Psi} - \lambda(\Psi\overline{\Psi})^2 \tag{15}$$

where the first term is that of the electromagnetic gauge theory of photons with the gauge 4-potential vector $\mathcal{A}_j \mapsto \mathcal{A}_j + \frac{1}{\alpha}\partial_j\theta$ and covariant derivative $D_k = \partial_k - i\alpha\mathcal{A}_k$, as introduced in (12). This Lagrangian is invariant for the local transformation $\Psi|_{\mathbf{r}_4} \mapsto \mathrm{e}^{i\theta(\mathbf{r}_4)}\Psi|_{\mathbf{r}_4}$, i.e., the gauge field $\mathcal{A}_j$ interacts with the field Ψ in such a way that the Lagrangian is invariant (local symmetry) under the gauge transformations of Ψ and $\mathcal{A}_j$. By considering now the same perturbation of Ψ around the ground state, $\Psi = (V_0+\eta(\mathbf{r}_4))\,\mathrm{e}^{i\xi(\mathbf{r}_4)}$, and plugging it in $\mathcal{L}$ in (15), we obtain:

$$\mathcal{L} = (-\frac{1}{4}F_{kj}F^{kj}+\alpha^2V_0^2\mathcal{A}_k\mathcal{A}^k)+(\partial_k\eta\partial^k\eta-4\lambda V_0^2\eta^2)+(V_0^2\partial_k\xi\partial^k\xi-2\alpha V_0^2\partial_k\xi\mathcal{A}^k)+c.c \tag{16}$$

where *c.c* are the rest of cubic and quartic terms and the first two terms in the parenthesis compose the Proca Lagrangian (2) of massive photon in the case of electromagnetic source-free case ($\mathcal{J}_j = 0$). To see particle's content, only the quadratic terms in this Lagrangian are interesting. The term $\alpha^2V_0^2\mathcal{A}_k\mathcal{A}^k$ in this case when $V_0 \neq 0$ shows that the gauge field $\mathcal{A}_j$ now has become *massive*, due to its interaction with the constant part V_0 of the Higgs field Ψ. The component $\eta(\mathbf{r}_4)$ of the Higgs field Ψ is massive due to term $4\lambda V_0^2 \neq 0$, while $\xi(\mathbf{r}_4)$ seems to be massless. However, $\xi(\mathbf{r}_4)$ is not physical particle but a function that has results from the freedom to "pick a gauge". This freedom can be used to set $\xi(\mathbf{r}_4) = 0$, so that $\Psi = V_0+\eta(\mathbf{r}_4)$, and this choice of gauge is called the "unitary gauge". We have eliminated Goldstone field ξ by taking advantage of the gauge invariance. This is what the current SQM theory means *the Goldstone boson is "eaten" by the gauge field.* To verify that indeed $\Psi = V_0+\eta(\mathbf{r}_4)$ defines a gauge field, it must be noted that this can be achieved by a gauge transformation with $\theta(\mathbf{r}_4) \equiv -\xi(\mathbf{r}_4)$, that is:

$$\Psi|_{\mathbf{r}_4} \mapsto \mathrm{e}^{-i\xi(\mathbf{r}_4)}\Psi|_{\mathbf{r}_4}, \qquad \mathcal{A}_j(\mathbf{r}_4) \mapsto \mathcal{A}_j(\mathbf{r}_4) + \frac{1}{\alpha}\partial_j\xi(\mathbf{r}_4) \tag{17}$$

However, with this "pick a gauge" fixing, $\xi(\mathbf{r}_4) = 0$, the gauge symmetry is removed from the Lagrangian. The field Ψ no longer have the freedom to transform under gauge transformation, because the one representation $\Psi = V_0 + \eta(\mathbf{r}_4)$ is fixed.

For this "unitary gauge", the Lagrangian density (16) becomes equal to:

$$\mathcal{L} = (-\frac{1}{4}F_{kj}F^{kj} + \alpha^2V_0^2\mathcal{A}_k\mathcal{A}^k) + \partial_k\eta\partial^k\eta - (4\lambda V_0^2)\eta^2 + c.c \tag{18}$$

Thus, by substitution $\eta(\mathbf{r}_4) = \Psi|_{\mathbf{r}_4} - V_0$, we obtain the following Lagrangian density:

$$\mathcal{L} = (-\frac{1}{4}F_{kj}F^{kj} + \alpha^2 V_0^2 \mathcal{A}_k\mathcal{A}^k) + \partial_k\Psi\partial^k\Psi - (4\lambda V_0^2)(\Psi - V_0)^2 + c.c$$

This Lagrangian now clearly shows that the "Higgs field" $\Psi|_{\mathbf{r}_4}$ is a massive field. There is no massless particles in this theory, because $\xi(\mathbf{r}_4)$ has completely disappeared from the Lagrangian and the gauge field of the 4-vector electromagnetic potential is massive as well (mediated by the massive photons) as follows from the quadratic term $\alpha^2 V_0^2 \mathcal{A}_k\mathcal{A}^k$ with mass $m_{\mathcal{A}} = \alpha V_0 \neq 0$ which $\mathcal{A}_k$ has acquired.

This mechanism, by which spontaneous symmetry breaking generates a mass for a gauge boson, was explored and generalized to the non-Abelian case by Higgs, Kibble, Guralnik, Hagen, Brout and Englert, and is now known as the Higgs mechanism.

The role of the "pick a gauge" fixing in the breakdown of the Goldstone theorem can give insight into the position of *gauge (local) symmetry* breaking w.r.t. *global symmetry* breaking. In current ensemble interpretation of the statistical theory of the Standard Model (SQM), three massless Goldstone bosons are generated, which are absorbed to give masses to the $W^{\pm}$ and Z gauge bosons. The remaining component of the complex doublet becomes the Higgs boson- a new fundamental scalar (0-spin) boson.

Remark: Such a solution with this "pick a gauge" can not be used if we consider Ψ as the particle's wave-packet of the energy density, where the complex component is the particle's pilot-wave which can not be a constant for the massive particles (only for the massless bosons it is constant phase). Thus, for the massive bosons theory provided in Section 3 we need an alternative approach to the Higgs mechanism.

2 Fadeev's Interepretation of the Higgs Mechanism

The question of the Higgs field's existence has been the last unverified part of the Standard Model of particle physics and, according to some, "the central problem in particle physics". In the Standard Model of SQM, the Higgs particle is a boson with no spin, electric charge, or color charge. It is also very unstable, decaying into other particles almost immediately. It is a quantum excitation of one of the four components of the Higgs field. A number of authors [11, 19, 20, 21] have been suggested, and Higgs himself, that the Higgs mechanism can be described without spontaneous symmetry breaking, in a gauge invariant independent way, from the fact that the Higgs mechanism relies on the *zero ground state value* of the Higgs field.

The procedure used previously to describe the Higgs mechanism, uses an explicit "pick a gauge" fixing, by requiring that $\Psi|_{\mathbf{r}_4} = V_0 + \eta(\mathbf{r}_4)$, thereby setting the imaginary part of ψ to zero. But this gauge fixing gets rid of the gauge symmetry and thus obscures the meaning of gauge symmetry breaking. However, Higgs demonstrated in the 3rd paper on the mass of gauge bosons in 1966 that the Higgs mechanism can be described in an alternative gauge-invariant way, that is, in the gauge independent accounts of the Higgs mechanism. This procedure for $SU(2)\times U(1)$, leaving $U(1)$ symmetry in the Lagrangian, is given recently in [9, 11, 19], but for the conceptual understanding of the role of gauge symmetry the $U(1)$ model (of electrodynamics) is sufficient, as follows. The starting point is again the $U(1)$ gauge invariant Lagrangian for Ψ^4 theory as in equation (15). Here the set of fields $(\mathcal{A}_j, \Psi)$ is transformed to the set of new fields $(\mathcal{B}_j, \Phi, \xi)$ by

$$\Psi|_{\mathbf{r}_4} \equiv \Phi(\mathbf{r}_4)\ \mathrm{e}^{i\xi(\mathbf{r}_4)}, \qquad \mathcal{B}_j(\mathbf{r}_4) \equiv \mathcal{A}_j(\mathbf{r}_4) - \frac{1}{\alpha}\partial_j\xi(\mathbf{r}_4) \tag{19}$$

where $\mathcal{B}_j(\mathbf{r}_4)$ is the 4-vector potential field and $\xi(\mathbf{r}_4)$ and $\Phi(\mathbf{r}_4) \geq 0$ are real scalar fields. These transformations look similar to the transformations in (17) that determined the "pick a gauge" fixing, but are not the same. The difference is that now $\xi(\mathbf{r}_4)$ is one of the *variable* fields. While in (17) after gauge fixing, the gauge transformation can not longer be applied to fields, now the gauge is not fixed and gauge transformation can be applied to the fields. Thus a transformation $\Psi \mapsto \Psi' = \mathrm{e}^{i\theta(\mathbf{r}_4)}\Psi$ and the gauge transformation $\mathcal{A}_j \mapsto \mathcal{A}'_j = \mathcal{A}_j + \frac{1}{\alpha}\partial_j\theta$ is transformed into

$$\mathcal{B}'_j = \mathcal{A}'_j - \tfrac{1}{\alpha}\partial_j\xi' = \mathcal{A}_j + \tfrac{1}{\alpha}\partial_j\theta - \tfrac{1}{\alpha}\partial_j\xi' \qquad \mathrm{e}^{i\theta}\Psi = \Psi' \equiv \Phi'\mathrm{e}^{i\xi'}$$

These transformations imply that $\mathcal{B}_j(\mathbf{r}_4)$ and $\Phi(\mathbf{r}_4)$ *are invariant* under $U(1)$, while $\xi'(\mathbf{r}_4) = \xi(\mathbf{r}_4) + \theta(\mathbf{r}_4)$, that is:

$$\mathcal{B}'_j(\mathbf{r}_4) = \mathcal{A}_j(\mathbf{r}_4) - \tfrac{1}{\alpha}\partial_j(\xi'(\mathbf{r}_4) - \theta(\mathbf{r}_4)) = \mathcal{A}_j - \tfrac{1}{\alpha}\partial_j\xi = \mathcal{B}_j(\mathbf{r}_4)$$

$$\Phi'(\mathbf{r}_4) = \mathrm{e}^{i\theta}\Psi\mathrm{e}^{-i\xi'} = \mathrm{e}^{-i\xi}\Psi = \mathrm{e}^{-i\xi}\Phi(\mathbf{r}_4)\ \mathrm{e}^{i\xi} = \Phi(\mathbf{r}_4)$$

From the transformation $\xi'(\mathbf{r}_4) = \xi(\mathbf{r}_4) + \theta(\mathbf{r}_4)$ it follows that the field ξ is a pure gauge variable. It is only one in the set of new fields that is not gauge invariant. Thus, the Lagrangian in (15) can be rewritten in terms of the new fields

$$\mathcal{L} = -\tfrac{1}{4}B_{kj}B^{kj} + (\partial_k\Phi + i\alpha\mathcal{B}_k\Phi)(\partial_k\Phi - i\alpha\mathcal{B}_k\Phi) - (i\mu)^2\Phi^2 - \lambda\Phi^4$$

where $B_{kj} = \partial_k\mathcal{B}_j - \partial_j\mathcal{B}_k$. The field $\xi(\mathbf{r}_4)$ does not appear in this description; it was factored out. So, all fields in this theory are now invariant under the $U(1)$ transformation, the $U(1)$ symmetry has no grip now and the ground state of the system is no longer degenerate. To describe now the perturbation around the ground state $\Phi_0 = V_0$, the field $\Phi(\mathbf{r}_4)$ is rewritten as $\Phi(\mathbf{r}_4) = V_0 + \eta(\mathbf{r}_4)$, with $\eta(\mathbf{r}_4)$ a variable field, so that $\mathcal{L}$ reduces to

$$\mathcal{L} = (-\tfrac{1}{4}B_{kj}B^{kj} + \alpha^2 V_0^2 \mathcal{B}_k \mathcal{B}^k) + (\partial_k \eta \partial^k \eta - 4\lambda V_0^2 \eta^2) + c.c$$

which is equal to that of the "unary gauge" Lagrangian in (18), obtained for the Higgs mechanism with spontaneous symmetry breaking. The Lagrangian contains the massive photon $\mathcal{B}_j(\mathbf{r}_4)$ and the massive component $\eta(\mathbf{r}_4)$ of the "Higgs field" $\Phi(\mathbf{r}_4) = V_0 + \eta(\mathbf{r}_4)$ (we will show in in Section 4 that this real scalar field can be substituted by the real positive density $\Phi = \sqrt{\Phi_m}$ of the particle's rest-mass energy-density Φ_m). The model is renormalizable from the gauge invariance of the Lagrangian $\mathcal{L}$ (a proof for this is established by 't Hooft at 1970).

Thus, this approach where spontaneous gauge symmetry breaking has no role, is more general and guarantee the renormalization, but also well suited for the IQM field theory of the particles developed in [2, 3, 4]. Both approaches, that earlier, based on the spontaneous symmetry breaking, and this new one based on the gauge invariant Higgs mechanism, have one crucial element in common: the non-zero vacuum expectation value of the field $\Phi(\mathbf{r}_4)$. The fundamental question that previous work for the Higgs mechanism did not answer is *why and how* the "Higgs field" has a non-zero vacuum expectation (average) value $\int \Psi\overline{\Psi}dV = \int \Phi^2 dV = \langle \Phi^2 \rangle$. In Faddeev paper [11], he writes:

"*Thus, one way or another we see, that the nonzero expectation value for the* Φ^2 *can be invoked without the Higgs potential. The fundamental question remains, is the origin of the excitations for the field* Φ. *In both interpretations the most natural answer is massless scalar - analogy of dilation in the first interpretation or kind of Goldstone model in the second. I hope, that more experienced phenomenologist can consider seriously this hypothesis.*"

My answer is that Φ is the excitation field with $\Phi^2 = \Phi_m$, where $\Phi_m(\mathbf{r}_4) = \Psi(\mathbf{r}_4)\overline{\Psi}(\mathbf{r}_4)$ *is the rest-mass energy-density of an observed massive particle* with the complex wave-packet field $\Psi(\mathbf{r}_4)$, for which the potential term of the Lagrangian density, (only) during the interaction with a boson, explained in Section 4, obtains the form of the Goldstone "Mexican hat" potential.

3 Basic Equations and Interaction Processes in the IQM Theory

Quantum mechanics, based on the Schrödinger equation is an epistemic statistical theory, here denominated as Statistical Quantum Mechanics (SQM), to differentiate it from the new part of the ontological quantum theory, provided in [2, 3] and [4], denominated Individual particles Quantum Mechanics (IQM). Both of them are necessary components of the quantum theory, as are the Classical Mechanics for Individual objects (ICM),based on the Newton equations, Hamiltonian-Jacobi equations or the Euler-Lagrange equation of motion of individual objects) and the Statistical Classical Mechanics (SCM), based on the Liouville equations.

In the IQM theory there is a deeper specification of the state of the particle, and in this approach to completion provided in [2], these states are specified by the energy-density distributions of a given particle in the Minkowski time-space. Such an ontic state, also not fully accessible (non fully observable by the measurements, and/or with non accessible small compactified higher-dimensions for the electric charge (5th timelike dimension with the coordinate $q_4 = ct_4$) and spin (6th spacelike dimension with the coordinate q_5), for example), has to represent the complete description of an individual elementary particle, in order to be able to compute from it all properties of a particle as its rest-mass, position, speed, momentum, total energy, etc...

It was shown [1, 7, 8, 2, 10] that, generally, any massive particle can be defined in the Minkowski time-space (we will not use the real higherdimensional expressions but only its reduced forms to the 4-D representation) with the signature $(+,-,-,-)$, by the complex wave-packet

$$\Psi = \Phi(t, \overrightarrow{\mathbf{r}})\mathrm{e}^{-i\varphi_T} \tag{20}$$

where $\overrightarrow{\mathbf{r}} = q_1\mathbf{e}_1 + q_2\mathbf{e}_2 + q_3\mathbf{e}_3$ (for the 3-D Minkowski space orthonormal basis vectors $\mathbf{e}_j$, with $\mathbf{e}_j \cdot \mathbf{e}_j = -1$ for $1 \le j \le 3$ and $\mathbf{e}_0 \cdot \mathbf{e}_0 = 1$ for the time-coordinate $q_0 = ct$) composed by two sub components: by the shape $\Phi(t, \overrightarrow{\mathbf{r}})$ of particle's body that is a real function which defines the real *rest-mass energy-density* $\Phi_m \equiv \Psi\overline{\Psi} = \Phi^2(t, \overrightarrow{\mathbf{r}}) \ge 0$, and by the de Broglie 'phase (pilot) wave' with phase $\varphi_T(t, \overrightarrow{\mathbf{r}_T}) = -\frac{1}{\hbar}S_{t_0=0}$, where $S_{t_0=0} = \int_{0,\overrightarrow{\mathbf{r}_0}}^{t,\overrightarrow{\mathbf{r}_T}} L(t', \overrightarrow{\mathbf{r}}, \overrightarrow{\mathbf{v}})dt'$ is the Hamiltonian principal function for the initial particle's position $(t_0, \overrightarrow{\mathbf{r}_0})$ and the current position at $t \ge 0$ (its barycenter) at $\overrightarrow{\mathbf{r}_T}(t) \equiv \frac{1}{\mathbf{1}_\Phi}\int \overrightarrow{\mathbf{r}}\Phi_m(t, \overrightarrow{\mathbf{r}})dV$, and particle's Lagrangian at time t', $L(t', \overrightarrow{\mathbf{r}}, \overrightarrow{\mathbf{v}}) = -E - \overrightarrow{\mathbf{v}}\,\overrightarrow{\mathbf{p}}$ where E is particle's total energy and $\overrightarrow{\mathbf{p}}$ its canonical (conjugate) momentum, and $\mathbf{1}_\Phi \equiv \int \Phi_m(t, \overrightarrow{\mathbf{r}})dV$ is the particle's invariant energy (equal to rest-mass energy m_0c^2 for massive particles and energy E_0 of a boson, measured in the frame in which massive source of this boson is in rest).

Thus, for a *free* (non accelerated) particle which propagates with constant speed v and momentum p, so that $\overrightarrow{\mathbf{v}}\,\overrightarrow{\mathbf{p}} = -vp$, with barycenter position $\overrightarrow{\mathbf{r}_T}(t) = \overrightarrow{\mathbf{r}_0} + \overrightarrow{\mathbf{v}}t$, we obtain that the phase change linearly in time $t \geq 0$,

$$\varphi_T(t) = \frac{E - pv}{\hbar}t \tag{21}$$

When a particle propagates in the vacuum with constant speed $\overrightarrow{\mathbf{v}}$ it has the time-invariant spherically-symmetric distribution [6], $\Phi_m = \frac{K}{\sqrt{r}}$, where $r = \|\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T\|$ is the distance from its barycenter $\overrightarrow{\mathbf{r}_T}$, corresponding to particle's hydrostatic equilibrium where each infinitesimal amount of particle's material body $\Phi_m(t, \overrightarrow{\mathbf{r}})$ is in rest w.r.t. particle's barycenter. However, generally, during an acceleration each infinitesimal amount of energy-density $\Phi_m(t, \overrightarrow{\mathbf{r}})$ moves with a different speed $\overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}})$ w.r.t. the group velocity $\overrightarrow{\mathbf{v}}(t) = \frac{d}{dt}\overrightarrow{\mathbf{r}_T}(t) = v_1\mathbf{e}_1 + v_2\mathbf{e}_2 + v_3\mathbf{e}_3$, with $v = \|\overrightarrow{\mathbf{v}}\| = \sqrt{v_1^2 + v_2^2 + v_3^2}$, of particle's energy-density wave-packet and it is shown [2] that is,satisfied the following relationship $\overrightarrow{\mathbf{v}}(t) = \frac{1}{\mathbf{1}_\Phi}\int \overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}})\Phi_m(t, \overrightarrow{\mathbf{r}})dV$, so we can introduce the variation-velocity of the particle's matter flux $\overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}}) = \overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}}) - \overrightarrow{\mathbf{v}}(t)$ at each space-time point $(t, \overrightarrow{\mathbf{r}})$ inside particle's matter (where $\Phi_m(t, \overrightarrow{\mathbf{r}}) > 0$). As shown in [2], during an inertial propagation when the particle is in a hydrostatic equilibrium, we have that Φ_m is spherically symmetric around particle's barycenter with $\overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}}) = 0$ in every point inside particle's matter, so that every infinitesimal amount of Φ_m propagates with the constant wave-packet group velocity $\overrightarrow{\mathbf{v}}$. Only during the particle's accelerations we have that $\overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}}) \neq 0$, so that particle's body changes dynamically its shape in time.

In the assumption [2] of the topology of the matter of an elementary massive particle, the wave-packet do not undergo a spreading, also when it changes its matter density distribution (i.e., its energy-density Φ_m), and tends to its stable stationary spherically symmetric distribution during inertial propagation in the vacuum. That is, the matter has some internal self-gravitational autocohesive force analogously to the peace of *perfect fluid* in the vacuum, so that at any instance of time, the 3-D space topology of particle's matter distribution, and consequently its compressible energy-density Φ_m is simply connected, closed, continuous and differentiable.

In what follows, for the Cartesian coordinate system, $\nabla = \mathbf{e}_1\frac{\partial}{\partial x} + \mathbf{e}_2\frac{\partial}{\partial y} + \mathbf{e}_3\frac{\partial}{\partial z}$

is the gradient (for $x \equiv q_1, y \equiv q_2$ and $z \equiv q_3$) so that the Laplacian is defined by $\triangle = -\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ (we are using positive-time metric signature (+,-,-,-)).

The Lagrangian density $\mathcal{L}$ of a particle [2], is given by

$$\mathcal{L} = \frac{\hbar}{\mathbf{1}_\Phi}(-\frac{\partial \varphi_T}{\partial t}\overline{\Psi}\Psi + \frac{i}{2}(\overline{\Psi}\partial_0\Psi - \Psi\partial_0\overline{\Psi} - \overline{\Psi}\overrightarrow{\mathbf{w}}\nabla\Psi + \Psi\overrightarrow{\mathbf{w}}\nabla\overline{\Psi})) \tag{22}$$

with previously introduced speed of particle's matter/enegy density $\Phi_m(t, \overrightarrow{\mathbf{r}})$

$$\overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}}) = \overrightarrow{\mathbf{v}}(t) + \overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}}) \tag{23}$$

and with derived Euler-Lagrange equation of motion

$$\frac{\partial \Psi(t, \overrightarrow{\mathbf{r}})}{\partial t} = -\omega_p \Psi(t, \overrightarrow{\mathbf{r}}) + \overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}})\nabla\Psi(t, \overrightarrow{\mathbf{r}}) - \frac{1}{2}(\nabla \cdot \overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}}))\Psi(t, \overrightarrow{\mathbf{r}}) \tag{24}$$

where $\omega_p = \frac{\partial}{\partial t}\varphi_T$.
Thus, each massive elementary particle satisfies the following Noether's conservation laws:
Analogously to the Euler first equation of fluid dynamics (continuity equation), which represents the conservation of mass, here we have the analog equation for the conservation of matter (that is of the particle's rest-mass energy),

$$\frac{\partial \Phi_m(t, \overrightarrow{\mathbf{r}})}{\partial t} + \nabla \cdot (\Phi_m(t, \overrightarrow{\mathbf{r}})\overrightarrow{\mathbf{w}}(t, \overrightarrow{\mathbf{r}})) = 0 \tag{25}$$

It holds also for bosons when they become unstable after an initial 'space explosion' and, consequently, assume the massive particle behavior and a finite but non-zero energy-density volume in open 3-D space. We need that the body of the particle Φ_m provides also the physical internal pressure $P(t, \overrightarrow{\mathbf{r}})$ (which is a non-geometrical property) in order to guarantee the hydrostatic equilibrium of the massive particles. The hydrostatic equilibrium of an massive elementary particle demonstrated that the body of this particle Φ_m is a material substance [6], which is fluid and elastic, and which can not be reduced to the time-space geometry.

Hence, in this IQM theory [2] for individual elementary particles based on energy-density wave-packets, the point-like particles are only the stable-state bosons when they propagate with speed of light in the vacuum, and with their energy-density distributed in higher compactified dimensions [3]. In Section 2.7 in [2], dedicated to the 3-D radial expansion of the bosons w.r.t. the direction of particle's propagation, to the tunneling and reflections, has been considered the cylindrical expansion of the massive boson with energy density Φ_m (that is, during the unstable boson's states where the variation-velocity $\overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}})) \neq 0$. The real physical hyperdimensional representation of the massless bosons energy-density, for a given instance of time t, for the Euclidean space point $\overrightarrow{\mathbf{r}} = \overrightarrow{\mathbf{r}_0} + \overrightarrow{\mathbf{c}}t$, is given by $\Phi_m = \Phi^2(\mathbf{r}_4, t_4, q_5) = \sigma(q_5)\ \delta(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}_0} - \overrightarrow{\mathbf{c}}t)$ where, $\sigma(q_5) = \frac{\mathbf{1}_\Phi}{L}$, with the length of the 6th dimension is $L = 4\pi R_5$, denotes the constant energy-density distributed in 6th dimension with radius R_5.

Thus, by integration of this hyperdimensional density over 6th dimension with coordinate q_5, from [3] we obtain the common point-like 4-D representation of the massless boson's energy-density in the 4-dimensional Minkowski time-space by the Dirac function (note that its pilot-wave phase is $\varphi_T = 0$),

$$\Phi_m(t, \overrightarrow{\mathbf{r}}) = \mathbf{1}_\Phi \delta(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}_0} - \overrightarrow{\mathbf{c}}t) \tag{26}$$

where $\mathbf{1}_\Phi$ is a constant (equal to a total energy $E = pc$ of a boson in the frame where the source of this boson is in the rest), which is consequently *only mathematically* correct point-like representation of the massless boson. In fact, now the total energy, for a given time-instance t, can be obtained by integration in the ordinary 3-D space, by $E = \int \Phi_m dV = \mathbf{1}_\Phi \int \delta(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}_0} - \overrightarrow{\mathbf{c}}t)dxdydz = \mathbf{1}_\Phi \cdot 1 = \mathbf{1}_\Phi$. However, it is not physically correct, because we would have an infinity density of energy Φ_m in the single point of the boson's barycenter $\overrightarrow{\mathbf{r}} = \overrightarrow{\mathbf{r}_0} + \overrightarrow{\mathbf{c}}t$. In such case, the Schwarzschild radius r_s would be greater (or equal) than the radius of the point (boson's barycenter) which is zero, so that the boson would become a black hole, which does not correspond to physical facts. Note that this fact can't happen in the case when we are using the complete 6-D expression for the wave-packet, where $\Phi^2(t, \overrightarrow{\mathbf{r}}, q_5) = \sigma(q_5)\delta(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}_0} - \overrightarrow{\mathbf{c}}t)$ is also physically composed expression where the energy density is only $\sigma(q_5)$ and there exists only in the 6th dimension and not in M^4, and hence the Dirac 'function' δ in the Minkowski time-space M^4 defines only the *position* of the boson and not its energy-density. In effect, by the integration in 6-D time-space of boson's energy density, its total energy is $E = \int \Phi^2(t, \overrightarrow{\mathbf{r}}, q_5)dq_1dq_2dq_3dq_5 = \int \sigma(q_5)(\delta(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}_0} - \overrightarrow{\mathbf{c}}t)dV)dq_5 = \int \sigma(q_5)dq_5 = \mathbf{1}_\Phi$.

So, from (26) the volume of the massless boson in the ordinary 3-dimensional space is equal to zero. Only in such conditions a particle can travel with the maximal possible speed of light. But the matter/energy of the boson exists also in such conditions: it is uniformly distributed only in the spacelike sixth dimension (used for the spin) where it propagates with a constant speed v_5. Consequently, the hidden matter of a boson in the compactified higher dimensions results in zero rest-mass in the ordinary flat Minkowski time-space and explains why the boson can propagate with maximal possible speed. During this massless stable-state, the gravitational anti-black-hole barrier acting in the boson's barycenter (in 3-D space) does not permit the leaking of the matter from 6th into ordinary 3-dimensional space.

We consider the vacuum as the perfect 3-dimensional space symmetry where each possible direction of the propagation has the same physical conditions. Thus, the propagation of the particles in the vacuum is inertial and the particle propagates along GR geodesics with constant speed as a stable particle[4]. The asymmetry due to the presence of an infinitesimal inertial particle in flat Minkowski spacetime is purely circumstantial, because the spacetime is considered to be unaffected by the presence of this particle. However, according to general relativity, the presence of any inertial entity disturbs the symmetry of the manifold even more profoundly, because it implies an intrinsic curvature of the spacetime manifold, i.e., the manifold takes on an intrinsic shape that distinguishes the location and rest frame of the particle. Note that, from the fact that the stable bosons have no matter/energy in the ordinary 3-dimensional (open) space, the stable bosons do not generate any local time-space curvature, differently from the fermions. Thus, the local time-space neighborhood of a massless boson is always a locally flat Minkowski time-space, differently from the fermions (and also unstable massive bosons). The fact that the stable bosons have no any curved island-metrics in the ordinary 4-dimensional time-space, results in missing of any physical resistance of the neighborhood time-space to their propagation (differently from the massive particles with energy-density present in the 4-dimensional time-space and, generated from it, curved micro-island metrics). Consequently, they propagate with maximal possible speed in the ordinary 4-dimensional time-space. Thus, the bosons have the point-like 4-dimensional structure corresponding to their position (barycenter), but physically their total energy-density is $\Phi_m(q_5) = \sigma(q_5) = \frac{1_\Phi}{4\pi R_5} = const.$

But there are the situations when a stable, stationary, boson becomes excited for a short interval of time, as in the situations when the *space symmetry* during its propagation is sharply broken. Thus, the time-space boundary conditions for the particle's propagation are drastically changed, by considering that particle's wave-packet is a time-space perturbation and, if such a perturbation meets another perturbation, it changes its form. These events we analyzed in details for the phenomena of refraction and 'wave-behaviors' of an individual

[4]Such a 3-D space symmetry during an inertial propagation of a massive particle causes a spherical symmetry of its stable energy-density distribution $\Phi_m = \frac{K}{\sqrt{r}}$, for $r \leq r_0$ in a sphere with a radius r_0

photon [2]. In all these situations a photon may change its momentum, direction of propagation and its velocity, without changing its total energy, because these 'interactions' are not based on collisions with another particles (as Compton effects, or annihilations), but on instantaneous 3-D space expansions of their geometric wave-packet scalar field Φ in the presence of a local sharply broken space symmetry. These are strong General Relativity effects correlated with the particle's 'micro-island' curvature metrics, caused by a dynamical changing of the boundary conditions in the local space around this particle.

The interactions between any two wave-packets (particles) can be obtained only by their local collisions. In dependence on their energy and velocities, they can produce a kind of Compton's effects (elastic collisions) in which they survive the collisions by changing their momentum and energy (with the conservation of total momentum and energy), or they can produce a total fusion with a possible creation of the new stable particles (in Feynman's diagrams).

Thus, for any two massless bosons with the Dirac function energy-distributions, it is impossible to have the collisions during their stable states, but only when they are excited and involved in their temporary 3-D "spatial explosions". Such 3-D spatial explosions can happen also when two stable particles are at a very small mutual distance, during which the ideal spatial symmetry for a free particle in the vacuum does not hold more for both of them. The bosons have a physical role as the intermediators between the massive particles (that have the rest-mass and the 3-D volume V_t greater than zero), that is, they are a quantum-source that generates the fields (the phenomena as electromagnetic fields are the statistical results of actions of a high number of photons). In the case when the bosons are massless (long range interactions as for massless photons) then we have no the significant interference between themselves. This situation can be obtained at the quantum level only if the collisions between photons, for example, are practically improbable. Consequently, a number of photons can coexist in the same small 3-D region of space without any significant direct interference between them, heaving contemporarily the collisions with fermions which have the rest-mass and volume V_t greater than zero. Also in such a situation, we can have the rare cases of the interference between the photons. In normal situations, these interferences statistically can be neglected, while in the cases of very strong field interactions (when the local density of photons is extremely high) these inter-boson's interactions are significant. Thus, we have the following assumption:
Interaction-dynamics Assumption: The interactions between the bosons

and fermions are realized always between two non-point like particles. That is, between a massive fermion and a massive unstable boson with a small but finite energy-density volume V_t.

□

It is demonstrated in [18] that in the IQM theory for a given individual particle, the total gauge 4-potential $\mathbf{A}^\mu = (\mathcal{A}_0, \mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3)$, in the 4-vector form $\mathbf{A}^\mu = \mathcal{A}_0\mathbf{e}_0 + \overrightarrow{\mathcal{A}}_g$, where $\overrightarrow{\mathcal{A}}_g = \mathcal{A}_1\mathbf{e}_1 + \mathcal{A}_2\mathbf{e}_2 + \mathcal{A}_3\mathbf{e}_3$, for particle's wave-packet $\Psi = \Phi e^{-i\varphi_T}$ with the time-dependent canonical momentum $\overrightarrow{\mathbf{p}}$ and total energy $E(t, \overrightarrow{\mathbf{r}}, \overrightarrow{\mathbf{p}})$ (equal to the Hamiltonian), is given on particle's barycenter (i.e., the trajectory) by

$$\mathcal{A}_0(t, \overrightarrow{\mathbf{r}_T}, \overrightarrow{\mathbf{p}}) = -\frac{1}{\alpha}(\frac{E(t, \overrightarrow{\mathbf{r}_T}, \overrightarrow{\mathbf{p}})}{\hbar} - i\frac{\nabla \cdot \overrightarrow{\mathbf{u}}(t, \overrightarrow{\mathbf{r}_T})}{2}), \qquad \overrightarrow{\mathcal{A}}_g(\overrightarrow{\mathbf{p}}) = \frac{\overrightarrow{\mathbf{p}}}{\alpha\hbar} \tag{27}$$

(where the time-component $\mathcal{A}_0$ is a complex value) and hence we can consider how the parallel transport at finite distances works, along a particle's path (of the particle barycenter) from the initial point $\mathbf{r}_T = (t, \overrightarrow{\mathbf{r}_T}(t))$, at the time-instance t, into the final point $\mathbf{r}'_T = (t', \overrightarrow{\mathbf{r}_T}(t'))$ at the time instance $t' = t + \triangle t$, for any finite time interval $\triangle t > 0$. From the fact that the parallel transport along a finite particle's *trajectory* $\gamma(\mathbf{r}_4, \mathbf{r}'_4)$ is given by (14), we have that

$$\Psi|_{\mathbf{r}'_T} = e^{i\theta}\Psi|_{\mathbf{r}_T} = e^{i\alpha\int_\gamma \mathcal{A}_k(z)dz^k}\Psi|_{\mathbf{r}_T} \tag{28}$$

where the local phase transformation θ, which from (27) is a *complex value*, is obtained by the path integral:

$$\theta = \alpha\int_{\gamma(\mathbf{r}_T,\mathbf{r}'_T)} \mathcal{A}_k(z)dz^k = \alpha\int_t^{t'} (\mathcal{A}_0(\tau, \overrightarrow{\mathbf{r}_T}(\tau))+\sum_{j=1}^{3} v_j(\tau)\mathcal{A}_j(\tau, \overrightarrow{\mathbf{r}_T}(\tau)))d\tau \tag{29}$$

Consequently, by the path integration of the phase along the particle's trajectory, we obtained the following result [18]:

Proposition 1 *The gauge 4-vector potential of the particle's filed $\Psi = \Phi e^{-i\varphi_T}$ satisfies:*

$$\frac{d}{dt}\ln\Psi|_{(t,\overrightarrow{\boldsymbol{r}_T}(t))} = i\alpha(\mathcal{A}_0(t, \overrightarrow{\boldsymbol{r}_T}(t))) + \sum_{j=1}^{3} v_j(t)\mathcal{A}_j(t, \overrightarrow{\boldsymbol{r}_T}(t))) \tag{30}$$

A 'parallel transport' (28) of this particle's filed along a finite curve of its barycenter $\gamma(\boldsymbol{r}_T, \boldsymbol{r}'_T)$, from the initial point $\boldsymbol{r}_T = (t, \overrightarrow{\boldsymbol{r}_T}(t))$ into the final point

$\boldsymbol{r}'_T = (t', \overrightarrow{\boldsymbol{r}_T}(t'))$, *where* $t' = t + \triangle t$ *for a finite time interval* $\triangle t > 0$, *produces the following local complex-phase transformation (29):*

$$\theta = -\varphi_T|_{\boldsymbol{r}_T}^{\boldsymbol{r}'_T} - i\ln\Phi|_{\boldsymbol{r}_T}^{\boldsymbol{r}'_T} = -\varphi_T|_{\boldsymbol{r}'_T} + \varphi_T|_{\boldsymbol{r}_T} - i\ln\Phi(\boldsymbol{r}'_T) + i\ln\Phi(\boldsymbol{r}_T) = -i\ln\Psi|_{\boldsymbol{r}_T}^{\boldsymbol{r}'_T} \quad (31)$$

In next section we will apply these results of the IQM theory of an indinvidual particle to Higgs mechanism.

4 Gauge Invariant Higgs Mechanism without Higgs Field in the IQM theory

The Higgs mechanism describes how the (general) gauge field $\mathbf{A}^\mu = (\mathcal{A}_0, \mathcal{A}_1, \mathcal{A}_2, \mathcal{A}_3)$ can be massive. First of all, from this equation, the gauge field on the particle's trajectory (a world line in the Minkowski time-space), that is, in the points $(t, \overrightarrow{\mathbf{r}_T}(t)) \in M^4$ is expressed by the observed massive particle complex field Ψ, so that this gauge field at least at the particle's barycenter is always massive field. Hence, the bosons of this gauge field when become very near to the moment of the collision with this observed massive particle (that is, to the particle's barycenter) must be in an unstable massive-boson's state. In this way, the interaction-dynamics assumption in previous Section (that the interactions between the bosons and fermions are achieved only by massive states of these bosons) is confirmed. The second important fact is that the Higgs mechanism is always presented during such interactions of fermions and bosons (i.e., the emission/absorbption of bosons). So, the Goldstone potential $V(\Psi\overline{\Psi})$ must be implicitly contained in the *gauge theory* of interactions for the particle's field Ψ and its Lagrangian.

Let us show that it is indeed so, and that the interaction of any massive particle field Ψ with any gauge-field boson (their collision), which modifies particle's pilot-wave phase φ_T (i.e., its total energy and momentum) and hence its path (trajectory), is *a manifestation* of the Goldstone "Mexican hat" potential. Here we will demonstrate that in this new IQM theory for an individual massive particle, we have the following facts:

1. The mathematical concept of the "*spontaneous symmetry breaking*" here is replaced by the physical concept of the *3-D symmetry breaking* of a massless (Goldstone) boson into a massive boson, when this boson collides (interacts) with this massive particle represented by the rest-mass

energy density wave-packet Ψ. Physically, the interactions between a boson (an intermediate particle of a given quantum field) with a massive particle happen always with the previous 3-D symmetry breaking for the boson's propagation (just before the collision with this massive particle). The perfect 3-D symmetry for a boson's propagation we have only in the conditions when it is enough far from the other massive particles, so that in the vacuum it has a stable form of a massless boson which propagates with the speed of light.

2. Thus, we do not need any kind of the "Higgs field", as supposed in the SQM theory in order to provide the mass to the Goldston massless bosons. In the IQM theory, it is exactly the rest-mass energy wave-packet Ψ of a given fermion, which interacts with the bosons of the gauge fields, and the rest-mass of such fermion is equal to $m_0 = \frac{1}{c^2}\int \overline{\Psi}\Psi dV$. The short-range bosons are massive bosons. However, also the ordinary massless bosons, before the impact with a massive particle, become massive (caused by the 3-D symmetry breaking on their trajectory), and hence any interaction between a fermion and boson happens always in the condition when this boson is in massive unstable state (thus with 3-D volume of their energy density).

3. The Goldstone "Mexican hat" potential $V = \mu^2\overline{\Psi}\Psi - \lambda(\overline{\Psi}\Psi)^2$ is dynamically generated always inside particle's Lagrangian density (22), $\mathcal{L} = \frac{\hbar}{\mathbf{1}_\Phi}(-\frac{\partial\varphi_T}{\partial t}\overline{\Psi}\Psi + \frac{i}{2}(\overline{\Psi}\partial_0\Psi - \Psi\partial_0\overline{\Psi} - \overline{\Psi}\overrightarrow{\mathbf{w}}\nabla\Psi + \Psi\overrightarrow{\mathbf{w}}\nabla\overline{\Psi}))$ when we have an interaction of this massive particle with a boson of a given field, with $\mu^2 \sim \hbar\omega_p > 0$ where $\omega_p = \frac{\partial}{\partial t}\varphi_T$. Such an interaction on particle's trajectory generates a positive parameter $\lambda = |\frac{1}{d}\frac{d\theta_R}{\delta t}| > 0$, where d is the rest-mass energy of the fermion in its barycenter (trajectory) and θ_R is the phase shift of the gauge symmetry transformation (the phase changing of the fermion's complex wave-packet Ψ, caused by the collision of this fermion with a massive boson of a given external field. The Lagrangian density of *free* massive particle does not have Goldstone "Mexican hat" potential component, because in this case of constant particle's speed $\lambda = 0$, and this potential component is reduced to $V = \mu^2\overline{\Psi}\Psi$.

4. The *global* symmetry of an individual massive particle corresponds to the *free* particle, when it propagates with a constant speed, so that the transformation under global $U(1)$ symmetry (5) is $\Psi \mapsto e^{iQ\theta}\Psi$, corresponding to the time translation $t \mapsto t + \triangle t$, with $\theta = -\triangle t$ and

$Q = \frac{E-pv}{\hbar}$. In fact, for a free particle, the rest-mass energy density does not change w.r.t. its barycenter $\overrightarrow{\mathbf{r}}_T(t)$, i.e., $\Phi_m(t, \overrightarrow{\mathbf{r}}) = \Phi_m(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)) = \Phi^2(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)) = \frac{K}{\sqrt{\|\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)\|}}$, with $\Psi = \Phi(\triangle \overrightarrow{\mathbf{r}})\, \mathrm{e}^{-i\varphi_T} = \Phi(\triangle \overrightarrow{\mathbf{r}})\, \mathrm{e}^{-i\frac{E-pv}{\hbar}t}$, where $\triangle \overrightarrow{\mathbf{r}} = \overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)$. So, for the same point inside particle's body, we have that in the translated time $t \mapsto t + \triangle t = t - \theta$,
$\Psi|_t = \Phi(\triangle \overrightarrow{\mathbf{r}})\, \mathrm{e}^{-i\frac{E-pv}{\hbar}t} \quad \mapsto \quad \Psi|_{t+\triangle t} = \Phi(\triangle \overrightarrow{\mathbf{r}})\, \mathrm{e}^{-i\frac{E-pv}{\hbar}(t-\theta)} = \Psi|_t\, \mathrm{e}^{iQ\theta}$.
So, each *local* symmetry transformation corresponds necessarily to a particle's acceleration, caused by the interaction of this massive particle with a boson of a given external field. Thus, for an individual particle in the IQM theory, the global and local symmetry transformations have a clear distinct physical meaning.

With this new IQM theory, we obtain a simplification of the Standard Model with a diminution of number of basic elementary particles: we do not need the Higgs bosons in our quantum theory, but each massless boson can be transformed into a massive boson, in particular during the emission of the bosons from a massive particle and during the absorption of the bosons, presented in details in the case of electrically charged particles in [10]. Now, with the dimensionally correct version of the Lagrangian density (22), we may rewrite particle's Lagrangian density for the *normalized* fields

$$\psi = \frac{\Psi}{\sqrt{\mathbf{1}_\Phi}}$$

(in order to have the direct relationship with the theory SQM and hence $\int \overline{\psi}\psi dV = 1$ as for the wavefunctions in the SQM) and hence from (22) and $\omega_p = \frac{\partial}{\partial t}\varphi_T$,

$\mathcal{L} = \hbar[\frac{i}{2}(\overline{\psi}\frac{\partial \psi}{\partial t} - \psi\frac{\partial \overline{\psi}}{\partial t} - \overline{\psi}\partial_{\overrightarrow{\mathbf{w}}}\psi + \psi\partial_{\overrightarrow{\mathbf{w}}}\overline{\psi}) - \omega_p\overline{\psi}\psi]$.

So, from the fact that the Lagrangian density $\mathcal{L} = 0$ (easy to verify), we multiply it with -1 to be used in the following form in next

$$\mathcal{L} = K_T + \frac{\hbar\omega_p}{2}\overline{\psi}\psi \tag{32}$$

where the first component $K_T = -\hbar\frac{i}{2}(\overline{\psi}\frac{\partial \psi}{\partial t} - \psi\frac{\partial \overline{\psi}}{\partial t} - \overline{\psi}\partial_{\overrightarrow{\mathbf{w}}}\psi + \psi\partial_{\overrightarrow{\mathbf{w}}}\overline{\psi})$ is kinetic part. The second part in (32) is the potential $V(\overline{\psi}\psi) = \frac{\hbar\omega_p}{2}\overline{\psi}\psi$ and it will be considered for the generation of the Goldstone "Mexican hat" phenomena in the form (4).

Let us consider a massive particle with normalized wave-packet ψ in an inertial propagation up to the time instance t_0 (with constant total energy E_0, momentum p_0 and speed v_0). Then, in a small interval δt, it has an interaction with an external field boson. So, during the open interval $(t_0, t_0 + \delta t)$ it is an accelerated particle, while after time $t_0 + \delta t$ it becomes again a free particle with new constant total energy E', momentum p' and velocity v. Thus, its Lagrangian at $t \leq t_0$ and $t \geq t_0 + \delta t$ is that of a free particle

$\mathcal{L}_{free} = K_T + \mu_0^2(\overline{\psi}\psi), \;\; for\ t \leq t_0$, and $\;\mathcal{L}_{free} = K_T + \mu_1^2(\overline{\psi}\psi) \;\; for\ t \geq t_0 + \delta t$
where $\mu_0^2 = \frac{\hbar}{2}\omega_p|_{t_0} = \frac{\hbar}{2}\frac{\partial\varphi_T}{\partial t}|_{t_0} = \frac{\hbar}{2}\frac{d\varphi_T}{dt}|_{t_0} = \frac{E_0 - p_0 v_0}{2} > 0$ and

$\mu_1^2 = \frac{\hbar}{2}\omega_p|_{t_0+\delta t} = \frac{\hbar}{2}\frac{\partial\varphi_T}{\partial t}|_{t_0+\delta t} = \frac{\hbar}{2}\frac{d\varphi_T}{dt}|_{t_0+\delta t} = \frac{E' - p'v'}{2} > 0.$
From the fact that the rest-mass energy density of a free particle is that of its hydrostatic equilibrium [6], we have that

$$\psi = \Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))\ \mathrm{e}^{-i\varphi_T} = \Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))\ \mathrm{e}^{-i\frac{E_0 - p_0 v_0}{\hbar}t}, \quad for \;\; t \leq t_0$$

$$\psi = \Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))\ \mathrm{e}^{-i\varphi_T} = \Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))\ \mathrm{e}^{-i\frac{E' - p'v'}{\hbar}t} \quad for \;\; t \geq t' = t_0 + \delta t$$

where $\Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)) = (\frac{K}{\mathbf{1}_\Phi\sqrt{\|\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)\|}})^{1/2}$ is that of the hydrostatic equilibrium. Thus, for a free particle we *have no* the "Mexican hat" form of the potential.

However, during the impact of the boson with this massive particle, in the open interval of time $(t_0, t_0 + \delta t)$, we have no more a free propagating particle but two possible scenarios: acceleration or deceleration of this massive particle during the collision with this massive boson. So, from Proposition 1 Section 3, we have that during this finite interval δt of time, the particle's wave-packet Ψ (thus also its normalization ψ) undergoes a local symmetry transformation $\psi \mapsto \psi\ \mathrm{e}^{i\theta}$ along its trajectory, such that the equation (31) reduces to, $\theta = \theta_R + i0 = -\varphi_T|_{t_0+\delta t} + \varphi_T|_{t_0}$, from the fact that at t_0 and $t_0 + \delta t$, the particle's shape is equal to that of the hydrostatic equilibrium $\Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)) = (\frac{K}{\mathbf{1}_\Phi\sqrt{\|\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)\|}})^{1/2}$, and hence, because of the free-particle property at t_0 and $t_0 + \delta t$:

$$\frac{d\theta_R}{dt} = -\frac{d\varphi_T}{dt}|_{t_0+\delta t} + \frac{d\varphi_T}{dt}|_{t_0} \tag{33}$$

By considering that on the particle's trajectory (that is, in the particle's barycenter), we have invariant rest-mass energy density (see the limit compressibility assumption in [6]), we define the positive constant:

$$d \equiv \frac{\Phi_m(t, \overrightarrow{\mathbf{r}}_T(t))}{\mathbf{1}_\Phi} = (\overline{\psi}\psi)_{(t, \overrightarrow{\mathbf{r}}_T(t))} > 0 \tag{34}$$

During this extremely short interval of interaction δt, we have two possible cases, for particle's acceleration or deceleration:

- Case 1, when $\frac{d\theta_R}{dt} < 0$, we define $\lambda = -\frac{\hbar}{2d}\frac{d\theta_R}{dt}$, $\mu = \mu_1$ and, from (33), $\omega_p' \approx \frac{\partial\varphi_T}{\partial t}|_{t_0} = \frac{\partial\varphi_T}{\partial t}|_{t_0} + \frac{d\theta_R}{dt}$, so that $\frac{\hbar\omega_p'}{2} = \mu^2 - \frac{\lambda}{d}$;
- Case 2, when $\frac{d\theta_R}{dt} > 0$, we define $\lambda = \frac{\hbar}{2d}\frac{d\theta_R}{dt}$, $\mu = \mu_0$ and, from (33), $\omega_p' \approx \frac{\partial\varphi_T}{\partial t}|_{t_0+\delta t} = \frac{\partial\varphi_T}{\partial t}|_{t_0} - \frac{d\theta_R}{dt}$, so that $\frac{\hbar\omega_p'}{2} = \mu^2 - \frac{\lambda}{d}$.

Hence, for the time-interval of the interaction with the (massive) boson, the non-free particle's Lagrangian density, at particle's trajectory $\mathbf{r}_4 = (t, \overrightarrow{\mathbf{r}}_T(t))$, becomes equal to

$$\mathcal{L}_{mh} \equiv \mathcal{L}|_{\mathbf{r}_4} = K_T + \frac{\hbar\omega_p'}{2}(\overline{\psi}\psi)_{\mathbf{r}_4} = K_T + \mu^2(\overline{\psi}\psi)_{\mathbf{r}_4} - \lambda(\overline{\psi}\psi)^2_{\mathbf{r}_4} \tag{35}$$

with the Goldstone "Mexican hat" potential with $V_0 \equiv -\frac{\mu^2}{2\lambda} = \begin{cases} -\frac{d}{1-(\frac{\mu_0}{\mu_1})}, & \text{in Case 1} \\ -\frac{d}{1-(\frac{\mu_1}{\mu_0})}, & \text{in Case 2} \end{cases}$ that is, with $V_0 < -d$, where d is normalized rest-mass energy density at particle's barycenter. So, we can assume as particle's ground state its initial hydrostatic equilibrium at t_0, before its perturbation caused by an impact with a boson, that is,

$|0\rangle = \Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))\, \mathrm{e}^{-i\varphi_T|_{t_0}} = (\frac{K}{\mathbf{1}_\Phi\sqrt{\|\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t)\|}})^{1/2}\, \mathrm{e}^{iQt}$, where $Q = -\frac{E_0 - p_0 v_0}{\hbar}$.

From the general global $U(1)$ transformation (5), it holds that the charge Q is its generator. Although the Lagrangian is invariant under this transformation, the ground state is not, and an infinitesimal $\theta = \delta t$ (which is a translation of the time for a finite interval δt of a free particle, when particle does not change its energy, momentum and speed, but only its pilot-wave phase φ_T which is periodic with a period 2π, that is, represents the circular change of the *angle* in direction φ_2 in the Fig.2) transforms from (5) like

$$|0\rangle \quad \mapsto \quad \mathrm{e}^{iQ\theta}|0\rangle \approx (1 + iQ\theta)|0\rangle \neq |0\rangle \tag{36}$$

and hence, from $Q|0\rangle \neq 0$, Q is the *broken generator* in this global $U(1)$ symmetry. In fact, after this global symmetry transformation for $Q\theta = -\frac{E_0 - p_0 v_0}{\hbar}\delta t$, we obtain the new state of the free particle in the time instance $t + \delta t$. Note that this ground state $|0\rangle$ corresponds to the zero external potential in the vacuum, where particle has an inertial propagation as a free particle. So, this state can be called as "vacuum state" of a given individual massive particle (as it is called in the SQM) as well.

Thus, in this simplest global $U(1)$ case, we have only one broken generator Q, but this does not correspond to the massless Goldstone boson. Instead, here in IQM, it corresponds to the *absence of* any interaction of this particle with *a boson.*
As in the SQM field theory, the oscillations around the *ground state*, or "vacuum" (corresponding to the hydrostatic equilibrium of a free particle), correspond to the real massive particle during its accelerations (with particle's 3-D expansion/compression around its spherically symmetric hydrostatic equilibrium). Let us consider now the perturbation

$$\psi' = (V_0 + \eta(\mathbf{r}_4))\ \mathrm{e}^{i\xi(t,\overrightarrow{\mathbf{r}}_T(t))} \tag{37}$$

around the ground state, where η and ξ (defined on the particle's trajectory $\overrightarrow{\mathbf{r}}_T(t)$) are real functions. Thus, it corresponds to accelerated particle's (normalized) wave packet $\psi' = (V_0 + \eta(\mathbf{r}_4))\ \mathrm{e}^{-i\varphi_T|_t}$, so that

$$\xi(t, \overrightarrow{\mathbf{r}}_T(t)) = -\varphi_T|_t \tag{38}$$

where the momentum, velocity and total energy of this particle change in the interval $t_0 < t < t_0 + \delta t$. It is easy to verify that, if we substitute ψ' in the Lagrangian density (35) on the particle's trajectory, we obtain that $\eta(\mathbf{r}_4)$ is massive field (as expected from the fact that $(V_0 + \eta(\mathbf{r}_4)$ is the square root of the particle's rest-mass energy density), without a necessity to introduce the new "Higgs field". The field $\xi(t, \overrightarrow{\mathbf{r}}_T(t))$ results massless, but not because it represents a massless Goldston boson. It is a massless field, because physically it does not correspond to another particle, and its negative value corresponds to the de Broglie pilot-wave *phase* of the observed massive particle ψ' in the IQM theory.

This perturbation above can be defined as a *local symmetry* $U(1)$ transformation, for any time-space point $\mathbf{r}_4$ such that the ground state $\psi|_{\mathbf{r}_4} = |0\rangle \neq 0$ (of the free particle in its hydrostatic equilibrium),

$$\psi|_{\mathbf{r}_4} \quad \mapsto \quad \psi'|_{\mathbf{r}_4} = \psi|_{\mathbf{r}_4}\ \mathrm{e}^{i\theta} \tag{39}$$

where $\quad \theta = \theta_R + i\theta_I = \xi(\mathbf{r}_4) - i\ln[(V_0 + \eta(\mathbf{r}_4)/\psi(\mathbf{r}_4)]$

$\qquad = \xi(\mathbf{r}_4) + \varphi_T|_{t_0} - i\ln[(V_0 + \eta(\mathbf{r}_4))/\Phi_0(\overrightarrow{\mathbf{r}} - \overrightarrow{\mathbf{r}}_T(t))]$,

and hence $\theta_R = \xi(\mathbf{r}_4) + \varphi_T|_{t_0}$, so that from (38), we obtain $\theta_R = -\varphi_T|_t + \varphi_T|_{t_0}$ as expected from Proposition 1, equation (31), from t_0 to t.So, this perturbation corresponds physically to the perturbation of the particle's rest-mass energy density from its hydrostatic equilibrium during the interval of interaction time $t_0 < t < t_0 + \delta t$.

The freedom to "pick up" the $\xi(t, \overrightarrow{\mathbf{r}}_T(t))$ by (38) is based on the fact that particle's de Broglie phase φ_T represents the *universal property of the nature* that the propagation of an object is governed by minimal action of its Lagrangian L, and such principle remains invariant is we add to L any real constant energy E_0. Hence, we can use $\xi(t, \overrightarrow{\mathbf{r}}_T(t)) = -\varphi_T|_t + \frac{E_0}{\hbar}t$, so that this "pick up" means that we selected the value $E_0 = 0$ to obtain (38).

Hence, any local symmetry breaking, which happens only during the collision of a massive particle with a boson of an external field (this boson, if it was previously massless, long-range, before the impact with this massive particles experiments a 3-D symmetry breaking on its trajectory during which it becomes a massive boson, without requiring any "Higgs field") generates the Goldons "Mexican hat" potential on the particle's trajectory. Moreover, we have no any appearance of the Goldon massless boson, and hence we have no physically any mysterious phenomena that it is "eaten" by the gauge field to become the massive boson. In the IQM, the $W^{\pm}$ and Z are ordinary short-range massive bosons. They obtain their mass by the process of expansion of their energy-density from the higher compactified dimensions into the ordinary open 3-D dimensions, and hence, from the massless boson with the zero 3-D volume of their energy-density, they become massive (and so inertial) particles with a small 3-D volume of their energy-density. Thus, we demonstrated the following property for an interaction of a massive particle with some external field boson:

Corollary 1 *During the interaction of a massive particle with a gauge vector boson (its emission or absorption), in an extremely small time interval* $[t-\delta t, t]$*, the Lagrangian density* $\mathcal{L}$ *on the trajectory of this accelerated particle corresponds to the Goldstone "Mexican hat" Lagrangian* $\mathcal{L}_{mh}$*, without introducing any new auxiliary "Higgs field".*

Proof: The previous derivation of the Goldstone "Mexican hat" Lagrangian in (35) from the particle's Lagrangian density (32) during interaction with a single boson during infinitesimal interval of time $[t, t + \delta t]$.
□

Let us see now how these results are correlated with the previously described gauge invariant Higgs Mechanism which used the transformation of the original fields $(\mathcal{A}_j, \Psi)$ into the set of *Faddeev's fields* $(\mathcal{B}_j, \Phi, \xi)$ in (19). From the fact that our gauge theory is defined only for the time-space points of the barycenter of the observed massive particle which interacts with bosons, we have to reduce also the equations used in the gauge invariant Higgs mechanism theory to the points lying on the particle's trajectory only. So, in the equations in (19), the phase $\xi(\mathbf{r}_4) \equiv \xi(t, \overrightarrow{\mathbf{r}})$ reduces to $\xi(t, \overrightarrow{\mathbf{r}_T}(t))$ which is only a function of time t, and hence we can set $\xi \equiv -\varphi_T|_t$ to the massive particle pilot-wave phase. Thus, the "Higgs field" Ψ in equation (19) reduces to the massive particle's field (wave-packet) $\Psi|_{\mathbf{r}_4} = \Phi(\mathbf{r}_4)\ \mathrm{e}^{i\xi(\mathbf{r}_4)} = \Phi(\mathbf{r}_4)\ \mathrm{e}^{-i\varphi_T}$.

From the fact that in our gauge theory introduced shortly in Section 3, the gauge field $\mathcal{A}_j$ is a massive field (of massive bosons), also this new gauge field $\mathcal{B}_j$ must be massive as required by the gauge invariant Higgs mechanism. But we also obtained that the "Higgs field" Ψ is not any new particular field, but only the field of the observed massive particle's wave-packet during its interaction with the gauge-field bosons. In effect, we do not need any new particular "Higgs field" and hence we do not need the so called Higgs bosons.

In the IQM theory we obtained that the "mass constant" μ is entirely determined by the observed massive particle, while the positive constant λ appears only during the collision of this massive particle (with its energy density Φ_m) with a massive gauge-field boson which produces a modification of massive-particle pilot-wave phase by the real component of $\delta\theta$ and the modification of the energy-density distribution of observed particle by the imaginary component of $\delta\theta$ (directly expressed by the components $\mathcal{A}_j$ of the gauge field). Thus, λ is a *coupling constant* of the mutual interaction of this observed massive particle and the bosons of the gauge field, and only in such an interaction we obtain the famous Jeffrey Goldstone potential $V(\Psi\overline{\Psi})$. So, the concept of "spontaneous symmetry breaking" can be substituted by a physical effect of the real 3-D space symmetry breaking during the propagation of a boson, when the presence of a massive particle on the boson's trajectory breaks the perfect vacuum 3-D space symmetry, and causes the 3-D space explosion of this boson during which the boson's energy-density is expanded from the extra compactified dimensions into the ordinary 3-D space by causing the mass-fixation of this boson.

This is the explanation of the Mass gap conjecture in Yang-Mills theory. So, the massive bosons $W^{\pm}$ and Z are the unstable states of the Goldstone massless weak-force gauge bosons. From the fact that these bosons are massive when they are emitted from the massive elementary particles and that in a very short time are absorbed by them, in such a short interval of time of their propagation they remain unstable short-range and hence massive during all their life-time.

In this new completed picture, the framework is different than in SQM: the Lagrangian $\mathcal{L}$ in (22) is the sum of $\mathcal{L}_{free}$ (of the free particle) and $\mathcal{L}_{gauge}$, and express the interaction of an individual massive particle with any individual boson (of these four bosons defined by Lagrangian component $\mathcal{L}_{gauge}$) at a given interval of time $[t, t+\delta t]$, just *during* the emission/absorbtion of this boson. Thus, the masses of the three bosons W^+, W^- and Z, computed by the SQM Pauli-matrices based Lagrangian are that of this new framework, from the fact that each rest-mass of these three bosons is invariant and remains equal also in the moment of direct collision with the observed massive particle (source or target object for these bosons). Thus, during this interval of time these massive bosons do not reach a perfect 3-D symmetry of the propagation in the vacuum. In the case of the photon there is a fundamental difference instead. In the SQM Pauli-matrices Lagrange framework, the state of this photon is its definite state after the electroweak interaction. That is, when the photon is relatively far from its source (massive particle) and hence it is already transformed from its massive unstable state into the ordinary stable massless photon (after an acceleration to the speed of light) which propagates in the vacuum (far from other massive particles) and hence in the conditions of the 3-D spatial symmetry. In the new IQM framework, this photon is considered just in the moment when it is emitted or absorbed, thus in its massive unstable state described by the $\mathcal{L}_{gauge}$ component.

5 Conclusions

An individual massive particle which interacts with a given gauge massive boson (during its emission or absorbtion), changes its pilot-wave phase φ_T by the real component $\delta\theta_R(t)$ of phase transformation $\delta\theta(t, \overrightarrow{\mathbf{r}})$ caused by this boson's gauge field (in a local gauge symmetry of the Lagrangian), during this boson's emission/absorbtion, thus on the particle's trajectory. The imaginary component $\delta\theta_I(t, \overrightarrow{\mathbf{r}})$ represents the modification of the distribution of the particle's energy-density during interaction with a boson.

This process is equal for any kind of interactions of the massive particles and the gauge bosons. Thus, it is a general process where the Goldstone "Mexican hat" appears in the Lagrangian density which describes the interaction of the massive particle's field Ψ (so that there is no any new "Higgs field") with any kind of vector bosons.

The Standard model in this completed theory is modified only by this fact that this theory do not need the Higgs boson, and by the fact that also QM for the particles, defined as the complex scalar fields $\Psi = \Phi(t, \overrightarrow{\mathbf{r}})\mathrm{e}^{-\varphi_T}$ (wave-packets with the pilot-wave phase φ_T, where $\Phi_m = \Phi^2$ is the rest-mass energy density in the 3-D space) is a deterministic theory as the classical mechanics.

This physical process explains the Mass gap conjecture in Yang-Mills theory.

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"*I think that the sting theory, for instance, did not show that it has future. Unfortunately, well, the new generation of young people in America, they where pressed very much by there own censors that they have to do only string theory... Do what you want, if it is possible. As much as you want, as is possible. And read lots.*"

In fact, all my published papers and last three books by Nova Science, cited here, are dedicated to this unsolved problem in physics, by developing the complementary part of statistical QM for individual particles (the IQM theory), that is, the microscopic description of the structure of matter.

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