Foundations of Physics (2022) 52:41
https://doi.org/10.1007/s10701-022-00556-y

Trying an Alternative Ansatz to Quantum Physics

Arend Niehaus[1]

Received: 5 January 2022 / Accepted: 28 February 2022

Abstract
We report to which extent elementary particles and the nucleons can be described by an Ansatz that is alternative to the established standard model, and can still yield predicted results that reproduce the observed ones, without using the formalism of quantum mechanics. The different Ansatz is motivated by the attempt to explain known properties of elementary particles as a *consequence of an inner structure*, in contrast to the approach of the standard model, where the properties are *ascribed* to point-like particles. Based on the assumption of the existence of photons, the possibility of the creation of fermion and anti-fermion in an interaction of two photons of equal energy is shown. The properties of these created elementary material particles are found to agree with the ones observed. Also the possibility of the creation of a neutron by interaction of two photons of equal energy is shown. In this case, the newly formed neutron rests in the center of the collision system as a combined system of the localized two photons. The created neutron is shown to have the known properties of the neutron, and in addition, to have a definite shape of definite size. The proton is described as the particle formed by decay of the neutron, also owning the observed properties, and in addition a definite shape. For all particles described by the Ansatz, their properties are consequences of an inner structure. The merits of the alternative description as compared to the standard model and the application of quantum mechanics are discussed.

Keywords Quantum mechanics · Particle physics · Particle structure

1 Introduction

In this paper we report on the attempt to describe the elementary particles, electron and positron, and the photon, in terms of "entities with internal structure". This Ansatz is of course alternative to the established quantum field theory (qft) and to the Standard Model of particle physics (SM). It also implies that the

✉ Arend Niehaus
arendniehaus@aol.com

[1] Utrecht University, Utrecht, The Netherlands

formalism of quantum mechanics (QM), which is generally used in all theoretical treatments of phenomena in microphysics, is not used. As a consequence, paradoxical quantum phenomena, such as uncertainty relation, wave-particle dualism, nonlocality, etc., do not arise. Insofar as our alternative Ansatz turns out to be successful, it may therefore establish a better understanding of phenomena in microphysics. We stress however that, there always should exist a corresponding description using the established theory.

The hope that, possibly, with the alternative Ansatz these paradoxical quantum phenomena find a natural, understandable, explanation, and that real properties of elementary particles can be explained by their internal structure, has been the main motivation for our attempt with the alternative Ansatz. In a similar way motivated, many physicists have proposed alternative descriptions of quantum phenomena since the invention of (QM). There exists a vast literature on this subject [see f.i. [1]], which we do not try to survey here. We only mention contributions directly related to the material presented here. A very early contribution is a model of the photon proposed by De Broglie [2]. In this model the photon is composed of two "half-photons" that move at the speed of light on a path forming a "double-helix". Gauthier developed, independently, recently a similar model, described in [1]. In these models the electron–positron pair of material fermions is proposed to be formed by splitting the photon into the two "half-photons" upon contact with matter. The observable main properties of photon and of the fermions are in these models correctly reproduced, although a superluminal speed of the "half-photons" is involved, and no explanation of the occurrence of the elementary charge (e) is offered. Models which explain the spin of the fermions by a helical motion of a "light-like" particle have been proposed by several authors [3–5]. All these models have in common that, they involve "automatically" the so called "Zitterbewegung" (ZBW), which arises also in the Dirac equation. This fact indicates clearly the close relation between the established description on the basis of (QM), and the "classical" models. The role of (ZBW) has been the subject of numerous theoretical studies. An analysis of its role in the Dirac theory by Hestenes [6] has led to his (ZBW)-interpretation of quantum mechanics (QM), which explains the complex phase arising in (QM) directly in terms of the phase of the (ZBW)-motion.

Our model—as formulated so far in several publications [7–10]—resulted from the attempt to explain the electron-spin ($\hbar/2$) in terms of the motion of a"light like particle" without rest mass, but with momentum ($p = m\,c$) on a closed path around a central point in space. It turned out that the average orbital angular momentum of the "entity" formed by this localization of the light-like particle becomes ($\hbar/2$). The rest energy of the "entity" formed is of course equal to ($p\,c = m\,c^2$). The closed path of the light-like particle is characterized by two frequencies, (i) the Compton frequency $\omega = c/L$, with $L = \hbar/m\,c$ being the reduced Compton wave length, an (ii) the (ZBW)-frequency $\omega_z = 2\omega$ appearing in the Dirac theory of the electron. The other known properties of the fermions, radius, magnetic moment (except for the g-2 anomaly), and De Broglie wavelength are also correctly predicted. The formalism of (QM), which is generally applied in theoretical treatments in microphysics, is not used in the model. Therefore, the typical phenomena connected with (QM), namely, wave-particle dualism, collapse of the wave function, uncertainty relation, and nonlocality, do not occur.

In a further step it was shown that, by localization of *two* equal light-like particles around a fixed point in space, a material particle of rest energy equal to the sum of the energies of the light-like particles can be formed, and that this particle owns the main properties of the neutron. Since the neutron decays into the proton, an electron, and an antineutrino, also properties of the Proton are obtained [10]. For both nucleons, the spin ħ/2 is predicted, and a charge radius equal to four times their reduced Compton wavelength. The radius for the proton determined in this way becomes 0.84123 fm, a value which coincides, inside the given uncertainty, with the value 0.84184(70) fm obtained from recent spectroscopic experiments by quantum electrodynamic calculations [11].

The above sketched Ansatz may, in our opinion, be judged as promising in view of the successes mentioned. On the other hand, there remains a central question: *why should a light-like particle perform a closed path around a fixed resting point in our three-dimensional space"?* This question we will address below, and we will see that it leads to a model of the photon. And we will further see that, with this model photon, the role of the photon as a building "entity" for elementary particles with internal structure becomes conceivable.

2 Photon

A photon has the following observed properties: energy (scalar) $E=\hbar\omega$, momentum $p=E/c$, and speed $v=c$ (vectors in the same but arbitrary direction), Spin $S=\hbar$ (vector in direction of its momentum). We attempt to interpret these properties in terms of an internal structure. The circular frequency (ω) suggests an intrinsic rotation in the plane normal to the momentum that causes the angular momentum. The normal to this plane is the rotation axis. In one point on this one dimensional line the rotation center is located. The simplest realization of such a rotation arises if two "entities" with the same, but opposite, tangential momentum circle about the center, as in the classical two particle problem. The two circling entities then compose our photon of energy ($\hbar\ \omega$) in its two-dimensional coordinate system. If we ascribe to each of the two momenta the energy [(p/2) c], the energy of the photon becomes $\hbar\ \omega = p\ c$. And if we assume the tangential speed of the "entities" on the circle to be (c), the radius of the circle (L) can be determined from the circular frequency $\omega=c/L$, using $\omega=E/\hbar=pc/\hbar$, as

$$L = c/\omega = \hbar c/pc = \hbar/p \tag{1}$$

This means, the radius of the circle is equal to the reduced Compton wave length $\hbar c/E$ of the photon, provided the equivalent energy $E=mc^2$ is ascribed to the photon.

The motion on the circle is caused by the interaction between the two "entities" on opposite positions, and at opposite velocities. This interaction must be attractive and compensate the centrifugal force, so that the distance remains constant and equal to (2L). The total energy (E) contained in the circle is the sum of potential energy and kinetic energy, each contributing (E/2). If we assume the attraction to be proportional to 1/distance, we arrive at the equation

$$\mathrm{const}/(2\mathrm{L}) = 1/2\hbar\omega = \hbar\mathrm{c}/2\mathrm{L}, \text{ so that const} = \hbar\mathrm{c} \tag{2}$$

Remembering that the elementary charge (e) is related to the fine structure constant $\alpha = 1/137.036$ by relation $e^2/\hbar c = \alpha$, we arrive finally at

$$\mathrm{Const} = \mathrm{q}^2 = \mathrm{e}^2/\alpha = 137.036\,\mathrm{e}^2 \tag{3}$$

Our interpretation of the observed properties of the photon thus leads to the result (3), which states that two photons having opposite speed are attracted by each other as if they had opposite charges (q). But this charge may not be considered as a *property* of the photon, like the electromagnetic charge (e). On the contrary, we will see that, at parallel momentum, the interaction of our two model photons vanishes.

In the following we want to formulate a mathematical representation of the model photon. In its two-dimensional plane it is formed by two "entities" of opposite charges (q) circling at a radius equal to the reduced Compton wave length around a fixed point on an axis perpendicular to the plane of the circle. Along this axis the fixed point moves at the speed of light in the direction of the angular momentum (ħ) of the circular motion. As viewed by an observer in three dimensional space, the instantaneous azimuthal orientation of the two "entities" remains fixed, so that the sum of *their* momenta is just momentum ($p = E/c$) in direction of the axis. The possible positions of the two "entities" during the time span of one period of the circular motion, $\tau = 2\pi/\omega$, may be visualized by a "static", i.e., *not rotating* backward double-helix of length $\lambda = 2\pi L$, and radius (L), moving at the speed of light in direction of its spin vector of length $S = \hbar$. When the double helix passes the observer, he observes the two-dimensional circular motion of the "entities". The positions are described by the vectors

$$\begin{aligned} \mathrm{r1} &= \mathrm{L}\left\{\cos\left(\omega\left[\mathrm{t}_0 - \mathrm{t}\right]\right), \sin\left(\omega\left[\mathrm{t}_0 - \mathrm{t}\right]\right), \mathrm{ct}/\mathrm{L}\right\}; \\ \mathrm{r2} &= \mathrm{L}\left\{-\cos\left[\mathrm{t}_0 - \mathrm{t}\right], -\sin\left[\mathrm{t}_0 - \mathrm{t}\right], \mathrm{c\,t}/\mathrm{L}\right\} \end{aligned} \tag{4}$$

with (t_0) the arbitrary time point when the photon passes the observer, and $\omega = c/L$ the frequency of the photon. In Fig. 1 the traces of r1 and r2 forming the static double-helix that moves at the speed of light, and the closed paths of the quanta, $R/2 = (r1 - r2)/2$, which form a circle around any fixed point on the axis when the static double helix passes. For the time span of $\tau = 2\pi/\omega$, the observer notices a wave-like disturbance caused by the charges (q).

Qualitatively, we may state that, we have explained the properties of the photon by an inner structure represented by the traces of the two constituent "entities" whose properties are the properties of a photon, except for their energy, which is half the energy of the photon formed.

We point out that, the model-photon has "automatically" no rest mass, because it is *defined* as an "entity" that moves at the speed of light in three dimensional space. In the two dimensions of its rotation plane, on the other hand, it is located at rest, and has rest energy (E), and equivalent mass $m = E/c^2$. The energy is *a property* of

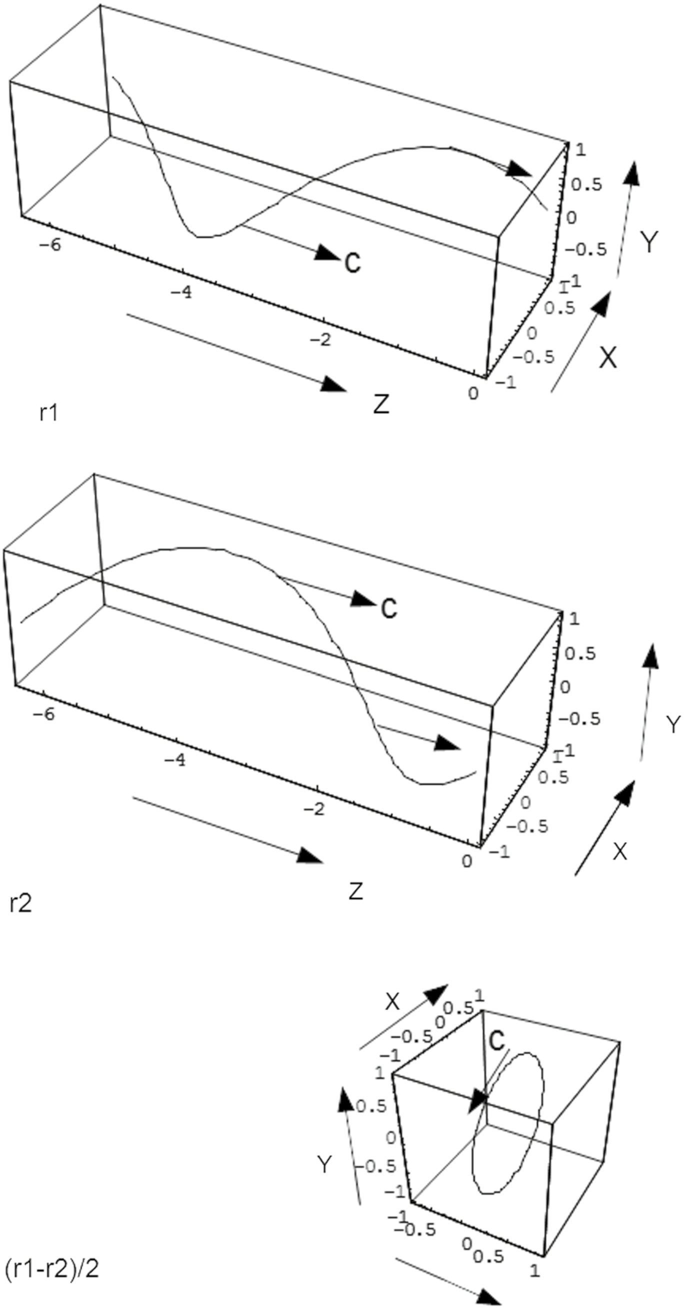

Fig. 1 Parametric plot of the traces r1 and r2 of the two quanta forming the static double helix which moves at speed (c) in Z-direction. The coordinates are given in units of the Compton wavelength (L). At any point in three dimensions on the axis of the double helix, the two quanta circulate in the X–Y-plane at speed (c) around the axis, as visualized by the trace (r1 − r2)/2

the photon in both, *two- and three dimensions*, because the two “entities” involved have momenta p = E/2c in *both* dimensions, and only their *path* is different. From this consideration it seems natural to assume that paths of the two “entities” around a fixed center in *three dimensions* should also be possible. The resulting “object” would then have *rest mass* (E). In other words, it would be an elementary “material” particle with internal structure. Below we describe our attempt to find the paths that form the material fermions with spin-1/2 in this way.

But before, we would like to point out remarkable consequences of our Ansatz that follow from the results so far. We notice that, the properties *assumed* for the two “entities” in our photon model, are exactly the same as those of the photon formed by them, except for their energy, which is half the energy of the photon formed. We therefore may conclude that, according to the model, a photon is represented by two photons of half the energy of the photon represented. These two photons are positioned on a circle of radius equal to the Compton wavelength of the photon formed. Since each of these two circling photons is again represented by two photons at a distance *of its* Compton wave length, and so forth, the very *existence* of one photon in two-dimensional space has an effect on the whole two-dimensional space up to infinite distances. In case of the existence of a resting “object” represented by two photons in closed paths around a fixed point in three-dimensional space, therefore, a similar effect on *the whole three-dimensional space* may be predicted. An identification of this effect in terms of the gravitational force would be interesting, because it would imply the direct connection between quantum-physics and general relativity, the gravitational field being caused by the “shielded” strong force between photons that have opposite momenta at distances of the order of their Compton wavelength.

3 Electron and Positron

If two photons of the same energy approach each other in such a way that, their static double helices described above (see Fig. 1) meet at some point in tree-dimensional space, we have two circles each circle describing two photons circling in the same plane around their center. For clarity, we will call these circling photons “quanta”. There are four such quanta. If the two centers are separated by a distance equal to twice the Compton wave length (L) of the colliding photons, we have a situation visualized in Fig. 2.

The angular momentum of the collision system is (ħ) in direction (Z) perpendicular to the collision plane. We notice that, at the appropriate relative phases of the circular motions, two of the four quanta will meet at the collision center during the collision event, which takes a time span of one period ($\tau = 2\pi L/c$). This “meeting” may be considered as the collision of two photons of equal energy and wave length. According to the established experimental knowledge on such a “Compton scattering” event, the wave length of the two photons may change, depending on the scattering angle. We consider the case of a scattering angle of 180 degrees, which is equivalent to an exchange of the quanta and their momenta. As indicated in Fig. 2, such a collision causes a “stopping” of the two photons in three dimensional space, and to a change of the internal motion of their two quanta. Since the angular

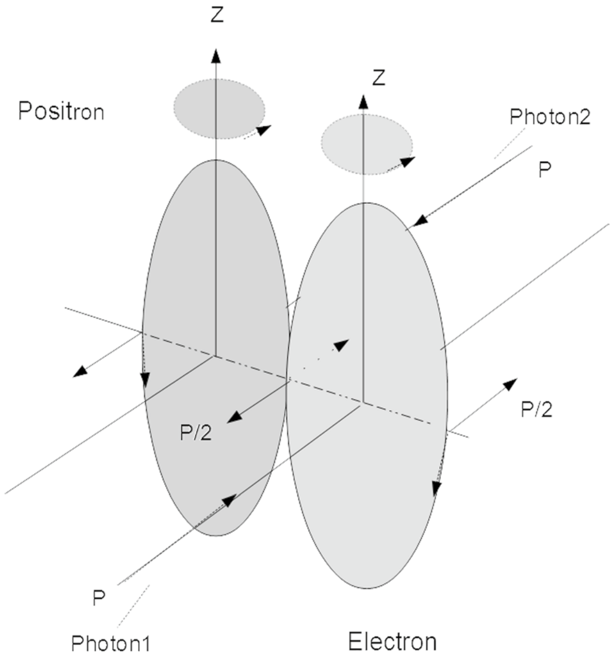

Fig. 2 The figure shows the situation when two photons meet in such a way that, during the collision, their quanta collide in the collision center. It is assumed that the two colliding quanta exchange their momenta, so that two not-interacting systems are formed, each being composed of two quanta that circle around a resting center. These two resting entities are the two fermions, each having spin-1/2 into the same direction perpendicular to the collision plane, so that the angular momentum (ħ) of the collision system is conserved

momentum of the total system is (ħ) perpendicular to the collision plane, the angular momentum of each of the two stopped systems has to be (ħ/2) in the same direction, as indicated in the figure. We will consider one of the two fermions, the other one being the anti-fermion. Within the model, we may require that, the speed of the two quanta involved have a speed along their path that is equal to the speed of light, that their path is closed around the center, and that the positions of the two quanta are opposite, i.e., $r2 = - r1$. These requirements are fulfilled by the following position vectors.

$$\begin{aligned} r1 &= L/2\left\{\left(1+\cos\left[\omega_t t\right]\right)\cos\left[\omega_c t\right],\ \left(1+\cos\left[\omega_t t\right]\right)\ \sin\left[\omega_c t\right],\ \cos\left[\omega_t t\right]\right\}, \text{and} \\ r2 &= -r1 \end{aligned} \tag{5}$$

In Fig. 3, the meaning of these quantities is indicated.

The frequency $\omega_t = 2c/L$ is the (ZBW) of the Dirac equation. We found the path by applying the photon model described above. A parametric plot of the position vectors of the two quanta during the period $\tau = 2\pi/\omega_c$, calculated with relation (5), is shown in Fig. 4a. The resulting path we will call a “String”. It represents the “entity”, which rests in (3D)-space and is formed by two photons in closed paths

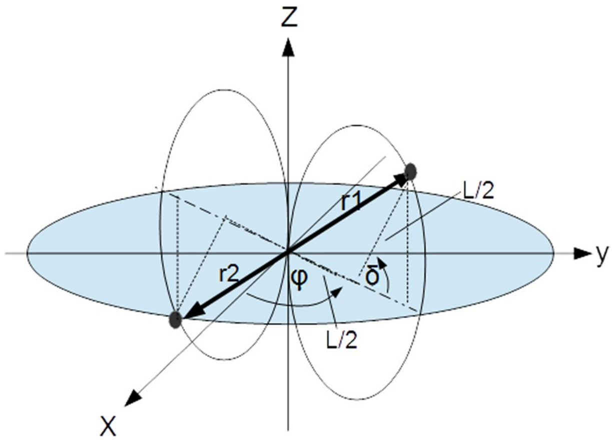

Fig. 3 The figure shows the quantities used to describe the paths r1, and r2, of the two quanta circling the resting center. Both quanta follow closed paths in opposite directions, so that they are attracted by each other with the strong force proportional to $q^2 = \hbar$ c. The angles (δ, φ) are correlated by $\delta = \omega_c$ t and $\varphi = \omega_t$ t, with $\omega_t = 2\omega_c$, and the rotation frequency around the (Z)-axis is $\omega_c = c/L$

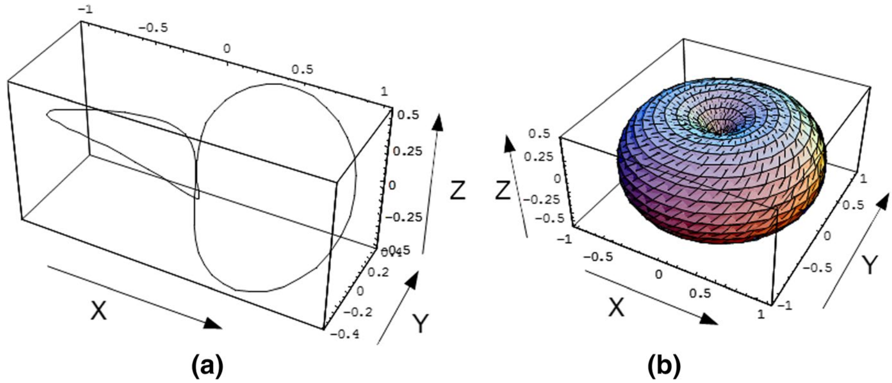

Fig. 4 **a** The String representig a single Fermion. It shows the paths of the two quanta that circle the center in closed loops, at opposite postions and with opposite speed. **b** The "statistical fermion"obtained by averaging over possible initial conditions. Its shape is a Clifford Torus on whose surface the paths of the quanta are positioned.The coordinates are given in units of (L)

around its center, so that the rest energy of the "entity" is just the energy E = 2 pc/2 of the two photons. It is worth noting that, a point on the String is determined by 10 parameters, 9 spatial coordinates and the time. Due to cylindrical symmetry, the azimuthal orientation of the entity is arbitrary, so that the "statistical" entity is the average over the azimuth. The shape that arises for the statistical entity using (5) is a so called Clifford torus, shown in Fig. 4b. On the surface of it, the paths of the two photons are positioned.

The String determines properties of the "entity" if these properties can be expressed as functions of time during the period ($\tau = 2\pi/\omega_c$). The properties are

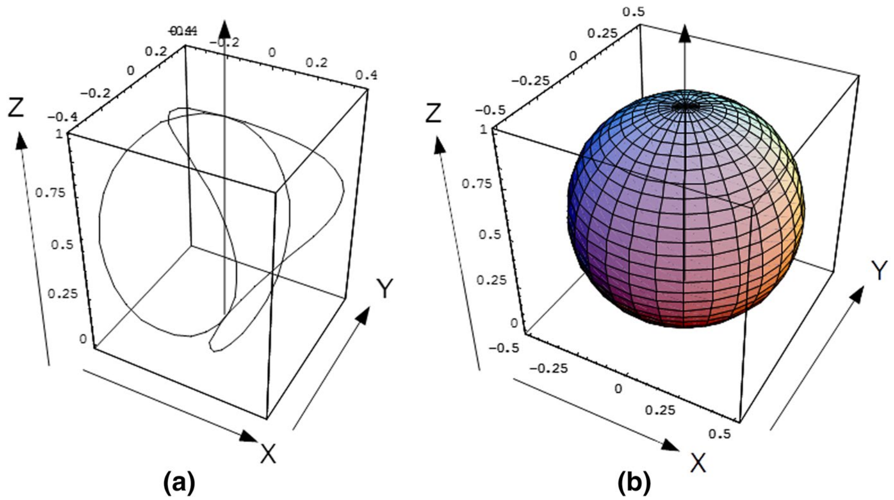

Fig. 5 **a** The angular positions of the angular momentum during one period for the string of a single Fermion. **b** The angular positions of the angular momentum during one period for the "statistical" fermion. The coordinates are given in units of (ħ)

then determined as an average over the period. To determine the average angular momentum, we need the time dependent momentum that each of the two quanta receives in the collision event. The contribution of the two quanta to the angular momentum of the entity have the same direction, so that the total instantaneous angular momentum of the entity becomes

$$\mathrm{S(R(t)) = Cross[R(t), P(t)]} \tag{6}$$

with $\mathrm{P} = 2\mu c = (m/2)\, c\{-\sin[\omega_c\, t], \cos[\omega_c\, t], 0\} = (m/2)\, v$, $\mathrm{R} = r1 - r2$, $\mu = m/4$ the reduced mass.The expression "Cross" in (6) indicates the cross product of the two vectors. The average as calculated using relations (5) becomes

$$\frac{1}{\tau}\int_0^\tau S(R(t)dt = \{0,\ 0,\ \hbar/2\} \tag{7}$$

The time dependent angular momentum can be visualized by a parametric plot of S(R(t)). It Is shown in in Fig. 5a, together with the azimuthal average, which is a sphere of radius (ħ/2) around the vector {0, 0, ħ/2}, as shown in Fig. 5b. The same average momentum vector is obtained for the anti-fermion.

We now assume that the described fermion is an electron with charge (− e). This assumption may be made in our model without a violation of constancy of total charge, because in the formation process the opposite charge (+ e) is created in the other fermion, the positron. A slight influence on the paths of the two quanta that exchange in the course of their "meeting", may imply the creation of opposite electromagnetic charges (± e) (see relation (3)) on the two fermions if the condition $r1 = -\ r2$ of their quanta is slightly violated. We postpone a more detailed discussion of this exchange process, and ascribe the charge (− e) to the fermion string (see (5)). This means, we ascribe (q − e/2) to r1, and (− q − e/2) to r2. The total charge is then (− e), and a current (I = − e v) arises along the closed loop of the quanta. This current creates a magnetic moment (μ) which can be calculated by integration over one period ($\tau = 2\pi/\omega_c$). The result is

$$\mu = \left(\frac{1}{\tau}\right)\int_0^\tau \frac{Cross[R, I]}{2} dt = e\frac{\hbar}{2m} = \mu_{\mathrm{B}}(\text{Bohr Magneton}) \tag{8}$$

This is the exact magnetic moment of the Dirac electron, including the g = 2 factor. So far, all results obtained for the model are independent of the mass. Therefore, the String (5) with the charge (− e), and the spin S = {0, 0, ħ/2}, may be considered to be a representation of the electron, if the mass is chosen appropriately. For the muon the equivalent magnetic moment is therefore predicted. Experimentally, the value of the magnetic moment has been determined with high accuracy, and is given by $\mu = \mu_B(1 + 0.0011600\ldots) = \mu_B(1 + a)$ [12]. The "anomaly (a)" is half the so called (g-2)-anomaly, and should be independent of mass according to (QFT). In contrast to this prediction, for the muon the experimentally determined anomaly is significantly different, and has a value of a = 0.001165 [Codata recommended value]. This fact indicates a mass dependent effect, which is up to date unexplained within (QFT).

In the frame of our model, a deviation from result (8) is expected, because the effect of the creation of charge (− e) on the string was neglected. Although a better approximation is probably possible, we will limit ourselves to the introduction of a slight change of the *distribution* of the charge (− e). Instead of ascribing (− e/2) to each quantum, we ascribe (− e/2)(1 + d cos[ω_t t]). This means, we introduce a dependence of the charge carried by the quanta on the distance from the center. The total charge is not changed in this way, and the calculated magnetic moment becomes

$$\mu = \mu_{\mathrm{B}}(1 + \mathrm{d}/2) \tag{9}$$

By setting $d/2 = \alpha/(2\pi) - (\alpha/(2\pi))^2$ the anomaly becomes a = 0.0011600…, in perfect agreement with the above given experimental value for the electron. The same value is of course predicted for the muon if the same mass-independent distribution is used. However, a mass dependent *distribution* does not seem to be *a priory* impossible. If d/2 is set to $d/2 = \alpha/(2\pi) + (\alpha/(2\pi))^2$, the anomaly becomes a = 0.001164…, in good agreement with the above given CODATA-value for the muon. As a speculation, we mention that, since the String includes the point R = 0, where the two quanta have the same position, the mass dependent effect of gravitation could perhaps explain the different anomalies. To our knowledge, (QFT) does not offer a solution to the problem.

In the following we will discuss briefly the so called (EPR)-paradox [13] in the frame of our model. The paradox for the case of a pair of electrons with opposite spin directions is described by Bell in [14]. It concerns the correlation of spin states of the single electrons after separation of the pair as predicted by (QM). These predictions are generally accepted to be in total agreement with experiment, but their interpretation implies a paradoxical "non-local" interaction of the separated electrons. Bell [14] showed with his famous Bell- inequalities that, no “realistic local hidden variable” model can yield the correct correlation, which supports the “non-locality” implied in (QM). Remarkably, our model is such a total realistic “local” model, and we will show that it still predicts the correct correlation for the separated pair of two electrons, and thus violates the Bell-inequalities. In addition, it offers a realistic explanation of the well-known “collapse paradox” implied in the description of measurement in quantum mechanics.

In our model the electron is represented by the string $R_P = (r1 - r2)/2$ (see relation (5) and Fig. 4a), and by the corresponding angular dependent spin vector (see Fig. 5a). Its partner electron of the pair with opposite spin is represented by the string $Rpp = - R_p$, and by the angular dependent spin vector represented by the trace shown in Fig. 5a rotated by 180° about the x- or y-axis. We point out a significant difference to the singlet state defined in (QM): In (QM) the singlet state has cylindrical symmetry with respect to the spin axis, while in our model the strings defining the state have azimuthal structure. The cylindrical symmetry is obtained by averaging over equally distributed azimuthal orientations of many systems, as shown in Fig. 4b for one electron of the pair.

The general experimental situation, for which the angular correlation between the probabilities (w1, w2) for the detection of the *same spin vector* for the two partners (1,2) of a singlet-system in two detectors (1,2) is determined, is the following: There is a source which produces singlet pairs of two fermions, and there are two detectors using magnetic fields that point into different directions n(ϑ1), and n(ϑ2). A coincidence condition allows to identify the partner particle (2), if the particle (1) has been measured. There is no influence on the partner particle during the time span between the measurements in the two detectors. In the fields of the detectors, there are only two possible states (+), or (−). If a particle(1) is detected in the (+) state in the field directed in direction n(ϑ1), the probability for particle (1) of the singlet system *selected* by this detection, is trivially w1+ = 1. If the partner particle resides in detector (2), it can be in the (+)-, or the (−)-state in the field in direction n(ϑ2), with probabilities w(2+), and (w2−). The correlation function is then given by c(β) = (w1+)(w2+) = w2+, with (β) being the rotation angle between the fields of the detectors.

This correlation function is easily obtained in our model from the static trace of the time dependent angular positions of the Spin vector trace (see Fig. 5a), as outlined below:

Anyone of the electrons of the singlet systems in detector(1), whose magnetic field is oriented in (Z)-direction of the figure, may be in the state characterized by the trace shown, whose average over the period yields $S = \hbar/2$. If it is detected, it has been with certainty in the (+) state, so that w1+ = 1. Due to the singlet condition, the partner particle(2) selected in this way is characterized by the trace that yields $S = - \hbar/2$. If it is detected in detector(2),whose field is parallel to the field of detector(1), it will with certainty be detected in the (−)state so that w2− = 1, and w2+ = 0, leading to c(0) = (w1+)(w2+) = w2+ = 0. If the rotation angle differs from zero, both, the (+)-, and (−)- state, are formed in detector(2), so that only an expectation function for the two states can be obtained from the Spin vector trace characterizing the partner(2) particle. This function we obtain from a calculation of the

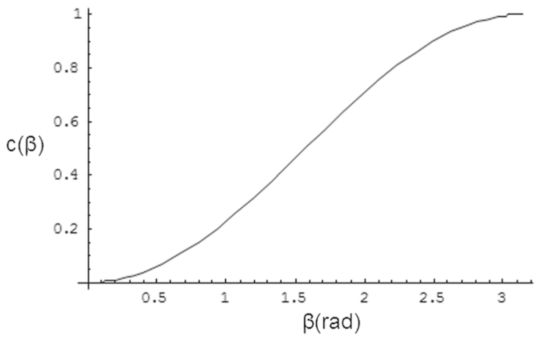

Fig. 6 The correlation function derived from the "realistic, local, hidden variable model". It shows the probability for detecting in detector(2) the same spin direction for the partner particle, as in detector(1) for the detected particle of a singlet-system. The function is identical to the function obtained by quantum mechanics, and violates the Bell inequalities

average of the spin angular momentum of partner particle(2) in direction of the field in detector(2). We obtain

$$F(\beta) = 1/\tau \int_0^\tau -S(t) \times n(\beta)dt = -\hbar/2 \cos[\beta] = \hbar/2\left(\sin^2\left[\beta/2\right] - \cos^2\beta/2\right) \tag{10}$$

In (10) the expression $-S(t).n(\beta)$ indicates the scalar product of the two vectors, i.e. the projection of the time dependent spin vector of partner particle(2) onto the direction of the field in detector(2).

Since the value of the angular momentum in both possible states is (ħ/2), the result (10) means that with probability $w2+ = \sin^2[\beta/2]$ the (+)-state is populated. And with probability $w2- = \cos^2[\beta/2]$ the (−)-state is populated. This leads to the correlation function

$$c[\beta] = (w1+)(w2+) = \sin^2\left[\beta/2\right] \tag{11}$$

A plot of the correlation function is sown in Fig. 6.

This correlation function is also the recently experimentally verified result, and the result obtained in quantum mechanics, where the correlation is obtained via the Born-rule as overlap between initial- and final state wave functions of the entangled system of two particles. As an interesting aspect we mention, that our result (11) can also be obtained as the overlap of initial- and final state- distributions of partner particle(2) in the field of detector(2). The "entanglement" necessary in (QM) is, in our description, implied in the strict correlation of traces of particle(1), and of partner particle(2), which are simply properties of the particles independent of their distance. The result (11) is obtained using probabilities, which is appropriate, because the experimental result is obtained by evaluating the outcome of many events. On the other hand, in reality, the single event ought to lead to *one* of the partner particle(2) states, *either the (+)-state, or the (−)-state*. This is the situation also implied in our model: for exactly known initial conditions of the static trace describing the partner particle(2), and for exactly known conditions of the time dependent magnetic field the particle(2) is subjected to when it enters the detector(2), it is, in principle, possible to calculate the transition from the initial state to *one of the two final states*. Since the magnetic field used in detector(2) is extremely weak compared to the field determining the trace of the particle(2), the transition may be viewed as a slow rotation of the trace from its original orientation into the orientation of one of the two possible final states. In a way, this slow transition predicted by the model, is an example of the "collapse" of the initial state wave function into the final state wave function appearing in the quantum mechanical treatment.

Based on our model, we conclude that the treatment of the measurement process by (QM) cannot be complete, because the wave function describing the singlet system does not distinguish azimuthal orientations of the system relative to the detector field, whose orientation defines a certain azimuthal angle. The reason why the predicted result of the correlation agrees with experiment, is due to the fact that, also the experiment does not distinguish between different azimuthal orientations of the systems selected by detection of one electron in derector1. Therefore, both, (QM) and the experiment, concern an *ensemble* of pairs, so that a description of a transition in a single event is impossible, and the measured result appears as a "collapse" of the initial state into one of the possible final states. In contrast, the model uses two strings with coordinated azimuthal structure to describe a selected single singlet pair, as outlined above. Since the detector2 is oriented in direction of a *certain* azimuthal angle, selected systems with *arbitrary* azimuthal orientation have different *relative* azimuthal orientations, leading to different contributions to the population of the possible two states in detector2. The actual measurement process in case of *a single electron* in a prepared spin-state may be described as the rotation of the string (see Fig. 4a) with its spin-vector in Z-direction, into an orientation having its spin-vector in *one* of the two possible spin states in the field direction of the detector. The magnetic field of the detector exerts a force on the string and "opens" its closed path inducing a rotation, until its spin is aligned with the field and the string is closed again. The spin vector $S=\hbar/2\{0,0,1\}$ (see (7)), after rotation into direction (β,ϕ) of the detector field, is expressed by $SD=\hbar/2\{\sin[\beta]\cos[\phi], \sin[\beta]\sin[\phi], \cos^2[\beta/2]\}$. A calculation of the average of (SD) assuming equal distribution of ϕ-orientations, yields

$$\mathrm{SD(av)} = \hbar/2\,\{0, 0, \hbar/2\cos^2\left[\beta/2\right]\}\ \text{for the}\ (+) - \text{state and}$$
$$\mathrm{SD(av)} = \hbar/2\,\{0, 0, \hbar/2\sin^2\left[\beta/2\right]\}\ \text{for the}\ (+) - \text{state}$$

meaning that, with probabilities $w(+)=\cos^2[\beta/2]$, and $w(-)=\sin^2[\beta/2]$, the spin of the detected electron is aligned with the two possible directions in the detector field.

This is of course the same result as obtained above (see (11)) for the experimental situation, but it is obtained by *averaging over single events* for each of which a smooth transition from the initial state to one of the observed states occurs. Due to the very short period $\tau=\lambda/c=0.8\ 10^{-21}$ s (λ: Compton wave length of electron) of the closed motion of the two constituents forming the string, the rotation of the string in the detector field involves many periods (τ), and only slightly opened strings. The string, therefore, remains virtually "intact" during the rotation, and the measurement process may be viewed as rotation of an electron with its intrinsic spin from initial to final state.

The main result we emphasize is the fact that our "local, realistic hidden variable model" yields the correct correlations in EPR- type experiments. A result which contradicts the Bell inequalities [14], and resolves the EPR-paradox [13]. Here it should be mentioned that, under the *assumption* of a spherical dependence of the orbital angular momentum, as shown in Fig. 6b, the result (11) has earlier been obtained [7], together with the statement that this violates the Bell inequalities. The model described here supports the earlier assumption. Finally, it should be mentioned that the failure of the Bell theorem has already been claimed [15]] for the case that "Clifford Algebra Valued Local Variables" are used in the Bell equations. This general mathematical statement is supported by our model which uses such variables.

4 Neutron and Proton

We consider again the situation where two photons of the same energy meet at a certain time point in three dimensional space (see Fig. 2). But in contrast to the assumption we made above to explain the creation of the fermions, namely that two of the four involved quanta exchange their momenta, we consider the case where they scatter with a scattering angle of 90 degrees into the (Z)-direction perpendicular to the scattering plane. According to the established theory of Compton scattering of two photons of the same energy the two photons keep their energy in this event. As a consequence of this scattering event in the resting center of the four quantum system, there remains a common rotation of all four quanta around the rotation axis (Z) with frequency $\omega_c = c/2L$, while the original frequency of the two photons, $\omega_t = c/L$, does not change. Following this argumentation we arrive at the following position vectors for all four quanta.

$$\begin{aligned} &r1 = L\{(1+\cos[\omega_t t])\cos[\omega_c t],\ (1+\cos[\omega_t t])\sin[\omega_c t],\ \sin[\omega_t t]\};\\ &r2 = -r1;\\ &r3 = L\{(1-\cos[\omega_t t])\cos[\omega_c t],\ (1-\cos[\omega_t t])\sin[\omega_t t],\ \sin[\omega_t t]\};\\ &r4 = -r3; \end{aligned} \tag{12}$$

The doubly occupied Strings r1, and r3 are visualized as parametric plot in Fig. 7a, b, and the String r1-r3 which represents the common correlated motion of all four quanta, is shown in Fig. 7c.

The shape of the entity formed is obtained as the average of the Strings R1 and R2 over initial conditions, i.e. as the average over the azimuth. It is again the Clifford torus (see Fig. 5). Its radius is $R_N = 2L = 2\ \hbar/(m\ c) = 4\hbar/(2mc) = 4\hbar/(M_N c)$ wit M_N being the mass of the four-quantum entity. The angular momentum of the entity is obtained by averaging the instantaneous spin vector Cross[R, p] over the period $2\pi/\omega_c$. The momentum vector (p) to be used in the expression of the spin vector is the momentum of the reduced mass of one of the two two-particle systems, and is given by $p = (m/4)\ c\{-\sin[\omega_c\ t], \cos[\omega_c\ t], 0\}$. The result is $S = \{0, 0, \hbar/2\}$. The two Strings contribute both $\hbar/4$.

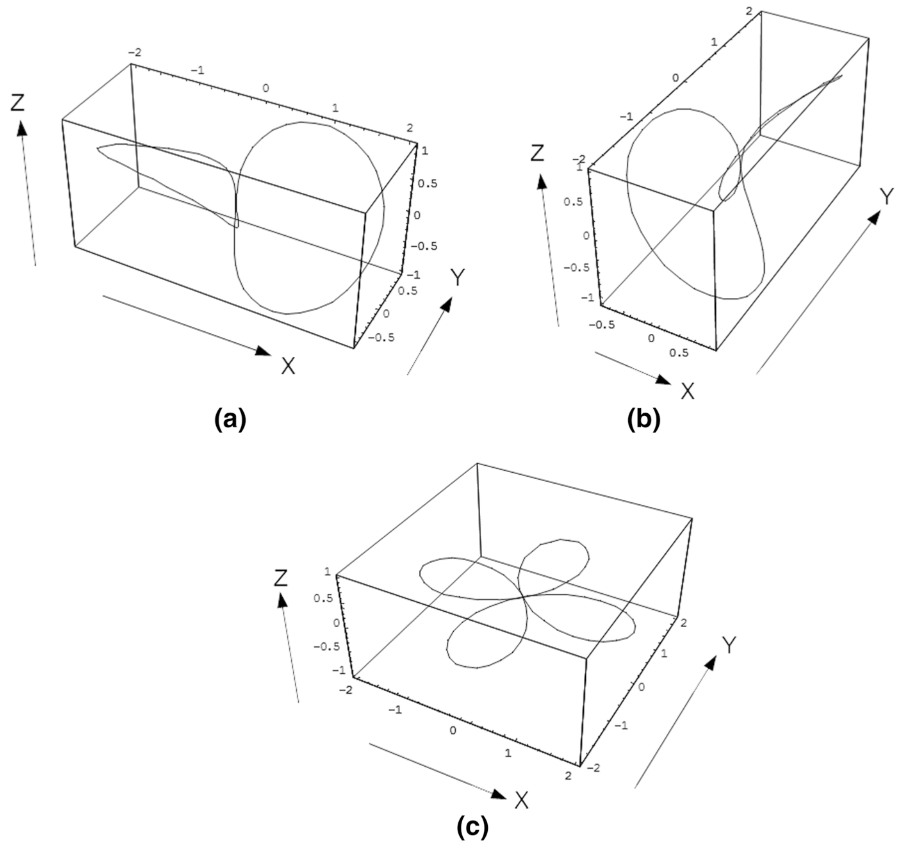

Fig. 7 **a** and **b** The two strings, R1 = (r1 − r2)/2, and R2 = (r3 − r4)/2, respectively, and **c**, the string R = R1 − R2

If the mass M_N is chosen to be the mass of the neutron, the neutral entity formed in the way outlined above, with spin = ħ/2, may be identified with the neutron. It has the shape of a Clifford torus and a radius (R_N) of four times its reduced Compton wave length. With the known value of that wavelength, the model therefore predicts for the neutron

$$R_N = 0.84008\,\text{fm} \tag{13}$$

Although the neutron has no charge, it has a magnetic dipole moment of $\mu_N = -1.9130\ \mu_{cl}$ with $\mu_{cl} = e\hbar/(2M_N)$. In our neutron model the Strings are neutral because the strong charges ± q involved compensate each other exactly, so that no currents arise during the closed path. However, from the outline given above of our model of the fermions, it is to be expected that, due to the interaction in the center of the system, a position dependent charge of the form ($Q = -e\ d\cos[\omega_t\ t]$) arises for the common string of our four quantum system. The total charge of the system then remains zero, while the strong charges (± q) involved are differently distributed, leading to a current (I = Q v). We now ascribe the charge (Q) to the String R = r1 − r3, and calculate the magnetic moment as the average of (Cross[R, Q v]/2) by integrating over one period ($\tau = 2\pi/\omega_c$). The result is

$$\mu_N = -2de\hbar/\left(2M_N\right) = -2d\mu_{cl} \tag{14}$$

If we set d = 1, the result is close to the experimental result given above. This suggests, that the charges (± e) to be ascribed to the Strings of electron and positron are caused in a similar way as in the case of the four quantum system. If we set $d = 1 - \left(\sqrt{\frac{\alpha}{4}} + \frac{\alpha}{8}\right)$, a value of the magnetic moment of the neutron of

$$\mu_N - 1.91275\,\mu_{cl} \tag{15}$$

is obtained, which agrees excellently with the experimental value.

Since the proton is formed from a neutron that decays into a proton, an electron, and an antineutrino, we assume as an approximation, that its representation by strings is essentially the same as for the neutron, except for the known mass difference and the charge (+ e). This means our proton model predicts a radius of four times the Compton wave length of the proton. With the known value of the Compton wavelength, this leads to the radius

$$R_P = 4\hbar/M_P = 0.84123\,\mathrm{fm} \tag{16}$$

which agrees within the given limits of error with the most recent experimental result [15]. This result has already been reported in our earlier paper on the proton model [10] where a "light like particle" was used instead of the model-photon introduced here. The magnetic moment of the proton is partly due to the positive charge (+ e), and partly due to an expected modified *charge distribution*, which does not contribute to the total charge, as introduced in the case of the neutron. A calculation using relations (12), results in a contribution of the positive charge (+ e) of (+ 4 μ_{cl}). Together with the contribution caused by the unmodified Charge distribution (see (14)), this leads to $\mu_P = 2\ d\ \mu_{cl}$. This differs significantly from the experimental value of $\mu_P = 2.7913..\ \mu_{cl}$. This difference suggests a modification of the charge distribution due to the extra charge. It is obviously weaker than in the case of the neutron, where $d = 1 - \left(\sqrt{\frac{\alpha}{4}} + \frac{\alpha}{8}\right)$ led to (15). If we set $d = 1/2 + \sqrt{\alpha} + 2\alpha$, we arrive at a magnetic moment for the proton of

$$\mu_P = 2.8000\,\mu_{cl} \tag{17}$$

Both model nucleons have the shape of a Clifford torus, which is obtained by averaging the Strings R1 and R2 over azimuthal angles. They have further an outer radius of four times their Compton wavelength, and an average spin angular momentum of ħ/2. In the absence of interactions, these properties are permanent. Remarkably, there is no hint of quarks, which compose the nucleons in the standard model of particle physics.

5 Summary and Conclusions

Our attempt to describe the photon with its observed properties in terms of an internal structure, has led to the conclusion that the described model photon has internal structure because it is formed by two photons of half the energy circling around each other in a two-dimensional plane. If the attractive force enabling the circular motion is described by opposite charges (±q) of the photons, this charge turns out be given by $q = \sqrt{\hbar c} = e/\sqrt{\alpha}$, and the radius of the circular motion is equal to the Compton wave length of the photon described. In three-dimensional space, the photon is described by a static double helix of the positions of the two constituent photons, which moves at the speed of light in an arbitrary direction, and causes at an arbitrary point a wave-like disturbance that lasts the time span of one period of the circular motion in two dimensions.

We showed that, in a collision under certain initial conditions two of these model photons of equal energy can create a fermion and an anti-fermion, both resting in space, and each having the rest energy of one of the photons. The created fermions have the properties known for electron and positron. The formation process is mass independent, and conserves the angular momentum of the collision system. The properties of the electron result from an internal structure which is represented by the closed path followed by the two constituent photons. This path is called a "String" which is occupied by two photons on opposite positions, and at opposite velocities. A position on this String is determined by 10 coordinates: 9 spatial coordinates, and the time. Calculations using the String yield (i) spin of (ħ/2), (ii) radius equal to the reduced Compton wave length of theparticle, and (ii) magnetic moment equal to one Bohr magneton. The anomaly is ascribed to an assumed charge distribution. The shape of the String, when integrated over possible initial conditions, is a Clifford Torus. If a singlet-system of two electrons is described using the model Strings for the (+)-state and the (−)- state, the correct angular correlations of spin directions measured in two different detectors are predicted. This implies a violation of the Bell inequalities.

It is further shown that, in a collision of two model photons of equal energy and opposite momenta at slightly different initial conditions as compared to the conditions that can lead to the formation two fermions, a resting system can result, which has the properties of the neutron. The radius of this compound system is four times its reduced Compton wave length, which amounts to $R_N = 0.84008$ fm. This is, to our knowledge, the first theoretical prediction of the neutron radius. The model neutron can be represented by two Strings that are centered around a common, resting origin. When integrated over possible initial conditions, the Strings become again a Clifford Torus. A magnetic moment of $\mu_N = -2\ \mu_{cl}$ is predicted. It is ascribed to a *distribution* of the charges (±e), which leads to a net charge equal to zero after integration over one period of the closed paths of the constituent photons.

The proton is described using the fact that it is formed via the neutron, which decays into a proton, an electron, and an anti-neutrino. We used the same Strings, except for the different mass, and we accounted for the extra charge (e). This description resulted in the prediction of a radius of four times the reduced Compton wave length of the proton $R_P = 0.84123$ fm, a value which agrees with the most accurate result obtained from spectroscopic experiments for the charge radius of the proton of $R_p = 0.84184(70)$ fm. A simple addition of the contribution of the extra charge (e) to the magnetic moment of the neutron leads to $\mu_P = 2\mu_{cl}$. It is shown that, a slight change of their charge distributions leads for both, neutron and proton, to perfect agreement of the calculated magnetic moments with the experimentally determined ones.

Considering the mentioned result we obtained with our alternative Ansatz, we conclude that, a rather comprehensible and consistent "quantum world" arises in which the photon with its internal structure plays the role of a building block for the formation of the material fermions, the nucleons, and for their internal structure which explains their properties. Quantum mechanical methods are not applied, so that the notorious paradoxes implied in these methods do not arise. Prominent examples are, the simple explanation of the EPR-paradox, and the explanation of the "wave function collapse" caused by measurement. Remarkable is the direct accessibility of some properties, f.i. radius and shape of the particles. In case of the neutron, the radius has, to our knowledge, not been predicted in the frame of the standard model, and experimental determinations have been limited to the charge radius. From binding properties in nuclei a value of ca. 1.7 fm is estimated for the diameter, so that the predicted value of 0.84008 fm, together with the predicted Clifford-Torus shape, is new information on a central particle.

Finally we point out that the model resulting from the Ansatz as presented here, does not account for the observed anomalies. From the way in which the mass dependence of the anomalies observed for electron and muon can be introduced into the model, it is suggested that, a more accurate treatment of paths of quanta at small distances could improve the predictive power of the model. Possibly, such a mass dependence could also be the answer to the unsolved question of the mass spectrum of existing elementary particles.

References

1. Gauthier, R.: Quantum-entangled superluminal double-helix photon produces a relativistic superluminal quantum-vortex Zitterbewegung electron and positron. J. Phys. **1251**, 012016 (2019)
2. De Broglie, L.: The Revolution in Physics: A Non-mathematical Survey of Quanta. Noonday Press, New York (1958)
3. Weyssenhof, J.: On two relativistic models of Dirac's electron. Acta Phys. Pol. **9**, 47 (1947)
4. Barut, A.O., Sanghi, N.: Classical model of the Dirac electron. Phys. Rev. Lett. **52**, 2009–2012 (1984)
5. Pavsic, M., Recami, E., Waldyr, A., Rodrigues, G., Jr., Maccarone, D., Raciti, F., Salesi, G.: Spin and electron structure. Phys. Lett. B. **318**, 481–488 (1993)

6. Hestenes, D.: The Zitterbewegung interpretation of quantum mechanics. Found. Physics **20**(10), 1213–1232 (1990)
7. Niehaus, A.: A probabilistic model of spin and spin measurements. Found. Phys. **46**, 3–13 (2016)
8. Niehaus, A.: Zitterbewegung and the electron. J. Mod. Phys. **8**, 511–521 (2017)
9. Niehaus, A.: Quantum interference without quantum mechanics. J. Mod. Phys. **10**, 423–431 (2019)
10. Niehaus, A.: An alternative model of proton and neutron. J. Mod. Phys. **11**, 285–293 (2020)
11. Pohl, R., Antonigni, A., Nez, F., et al.: The size of the proton. Nature **466**, 213–216 (2010)
12. Odom, B., Hanneke, D., D'Urso, B., Garielse, G.: New measurement of the electron magnetic moment using a one-electron quantum cyclotron. Phys. Rev. Lett. **97**, 030801 (2006)
13. Einstein, A., Podolski, B., Rosen, N.: Can quantum-mechanical description of physical reality be considered complete? Phys. Rev. **47**, 777–780 (1935)
14. Bell, T.S.: On the Einstein-Podolski-Rosen paradox. Physics **1**, 195–200 (1964)
15. Christian, J.: Disproof of Bell's theorem by Clifford algebra valued local variables, https://arxiv.org/abs/quant-ph/0703179 (2010). Accessed 22 Apr 2010