Home

Yes, Virginia, there is a Higgs field

On the arXiv, Khamidbi Beshtoev has published a paper arguing that the electroweak Higgs mechanism can’t have a direct physical realization. The Higgs mechanism is what gives mass to the elementary particles in the standard model of particle physics. Intensive collider searches for the Higgs boson, the particle associated with the Higgs field, are under way. As yet, this particle hasn’t been seen.

When they try to describe the Higgs mechanism in a nonmathematical way, physicists usually picture space as full of Higgs bosons, which by colliding with the other particles, exert a drag on them, causing them to travel at less than the speed of light, thereby making them massive. Beshtoev points out that the elementary particles have exactly the same masses at every point of the universe. If they get their masses by bumping into Higgs bosons, then the Higgs bosons must be distributed uniformly throughout the universe with a precision that is so great as to be distinctly unphysical. Also, if the Higgs field is real, he says, its energy density would have to be $2(10^{49})$ GeV/cm^3, which is 10^{53} times the observed energy density of the universe. Therefore, while the Higgs mechanism works perfectly in the mathematics of the standard model, it can’t be physical.

If the Higgs boson isn’t physical, it won’t be found by either the LHC or the Tevatron, and indeed, as reported by Tommaso Dorigo at *A Quantum Diaries Survivor*, the Tevatron has virtually excluded it between 160 and 170 GeV, right in the middle of the remaining mass range that hasn’t already been excluded experimentally. Should one worry?

According to the inflaton spacetime model, the answer is, “No worries, mate!” The problem is not with the standard model, nor is it with the Higgs field, which does exist. Instead, the problem is with the popular interpretation of the Higgs mechanism. The basic derivation of the standard model says nothing about Higgs bosons. What it says is that elementary particles have mass because the *vacuum expectation value* of the Higgs field is not zero. It says that the Higgs is a scalar field. No scalar particle is known to exist, so it should come as no surprise that the Higgs is not a particle field. The elevation above sea level is a scalar field defined on the surface of the earth, but no one would claim that there are “elevation bosons.” The vacuum expectation value of the Higgs field is a number, and while it does fluctuate, the fluctuations are so small that we aren’t able to observe them, so within experimental accuracy, elementary particle masses are exactly the same whatever their locations.

The problem can also be viewed as a result of the ontology of quantum field theory, which says that the basic things that exist are quantum fields and particles are just fluctuations or bundles of energy and momentum of the fields. Once you accept this ontology, everything is a field, and every field is a particle field. But scalar fields are not particle fields.

So what is the Higgs field, exactly, physically? First, some background on the inflaton spacetime model.

Inflaton Spacetime Model

In this model, spacetime is a random lattice of discrete points. Points are quantum objects or states that are completely described by quantum numbers called *position*, *spin*, and *time*. These are *intrinsic quantum numbers*. There is no requirement that between any two points there be a point with an intermediate position or time quantum number. There is no background spacetime. Time and space are illusions. Only points exist. Points are not particles, having neither mass nor momentum. They are zero-dimensional quantum objects whose position, time, and orientation are all random. The random orientation results in their having an apparent spin, which is quantized, and in this model, points are identical mixed states of spin-1/2 fermions and spin-1 bosons. The fermions and the bosons can be considered to form separate fields, and the fields are coupled because of the mixing. The bosons obey Bose-Einstein statistics, so they tend over time to seek the same quantum state. Because of the coupling, the bosons drag the fermions with them. This is gravity. The fermionic points are pulled together by gravity, but they avoid each other because they are identical fermions and obey Fermi-Dirac statistics (Pauli exclusion principle). This *degeneracy pressure* holds them apart. At equilibrium, they are close enough together that each point is trapped in a small volume of space, unable to escape because it is surrounded by other points that it must avoid. Time is also discrete in this model. Within its small potential well, each fermionic point takes a random position at each time tick. Each point well is assumed to be roughly spherical and have a radius equal to the Planck length, which is the mean distance between adjacent points. The average time interval between ticks is the Planck time.

Within each well, the point takes a random position at each time tick. Thus, it appears to vibrate. This vibration is referred to as quantum fluctuations of the vacuum, or zero-point energy. Considering each point as a Schrödinger object in an infinite spherical well, this zero-point energy or ground state energy is inversely proportional to the radius of the well and the mass of the object. Points don't have mass, but they look something like particles, so we will impute to them a "mass" of E/c^2. We then find that for a well radius equal to the Planck length, their ground state energy is $\pi/2^{1/2}$ times the Planck energy, $1.2211 \cdot 10^{19}$ GeV. Every point can also have higher energy levels in increments of the ground state energy, so the first excited state of a point has an energy equal to twice the ground state energy. Energy at a fermionic point in excess of the ground state energy is associated with a fermionic particle at that point (but no particle has the Planck mass, for reasons that will become clear later). A particle associated with a point in its first excited state is stable, since the excess energy has nowhere to go except to another point, in which case the particle moves but does not decay.

Because the points are identical, spacetime will look the same whether the point in a given well is the same point or a different point from one time tick to another. In other words, there is a nonzero probability that points can move, and in this model, they do move. They have two velocity eigenvalues: zero and the speed of light, corresponding to either no change of wells from one time tick to the next or a change of one well in any direction in one time interval. (This begins to look a little like an Ising model, but it isn't.)

A stationary electron is carried by a fermionic point that is in its first excited state and whose average position is constant. A neutrino is carried by a point that is in its first excited state and is always moving. A moving electron is a carried by a point that is in its first excited state and is usually stationary, but sometimes moves (a point in a mixed velocity state). If all fermionic points were stationary, nothing could move, only electrons would be possible, and they would all have a mass on the order of the Planck mass. If all fermionic points moved at the speed of light, only neutrinos would be possible and nothing could have mass.

Higgs Field

In the standard model of particle physics, the Higgs field is an isospin or SU(2) doublet. Each of its two components is a complex field made up of two scalar fields. Thus, there are four scalar fields φ_i, where i = 1, 2, 3, 4. The potential energy of the Higgs field has a minimum at a finite value of the field. The field evolves to this value. However, many choices of the four scalar fields will satisfy this condition and in the standard model the choice is that three of the four fields are zero and $\varphi_3 = v + h(x)$, where v is called the *vacuum expectation value*, and h(x), representing the fluctuations of the field about its vacuum expectation value, is the Higgs boson field. The masses of the electron, the gauge bosons W and Z, and the Higgs boson are then found to depend on the vacuum expectation value v.

In the inflaton spacetime model, the field φ_3 is the average energy of a fermionic spacetime point, imputing an energy of $\pi/2^{1/2}$ times the Planck energy to a stationary point and zero energy to a point that moves at the speed of light. These are imputed energies based on the geometry of spacetime. We never see them because we only see particles, not points.

The potential energy of this field would be very high if all fermionic points were stationary, and it would be zero if all points were moving points. Therefore, the expectation value of the field evolves towards zero. However, if all points were moving points, we would lose all information about the positions of individual points and we would have a kind of condensate in which all points are in the same quantum state. This is forbidden for fermions. An expectation value of zero is therefore forbidden, so the potential energy has an infinite barrier at $\varphi_3 = 0$. Hence the field settles at a vacuum expectation value v that is greater than zero. The vacuum expectation value v is found experimentally to be about 246 GeV. In our discrete model this means that there is one stationary point for every $1.1 \cdot 10^{17}$ moving points.

It is precisely because the vacuum expectation value of the Higgs field is not zero that fermionic points can have a zero-velocity eigenstate, so they can move at less than the speed of light and therefore have mass. They don't get mass by bumping into Higgs bosons. It is precisely because zero-velocity fermionic points are plentiful and not an *infinite distance apart that gauge bosons have a finite range and therefore have mass. They don't have mass because the Higgs bosons slow them down.*

Higgs Boson Mass

The electroweak Higgs boson is the only Standard Model particle that has not been seen experimentally. Its mass is not predicted by the Standard Model. The most likely value based on all experimental data gathered to date is said to be about 89 GeV with a large uncertainty of +38 and -28 GeV. This is in a mass range that has already been excluded by accelerator experiments. Other estimates place the Higgs mass between 114 and 170 GeV or so. The upper end of this range also appears to have been excluded.

As explained above, in the inflaton spacetime model Higgs bosons are not really particles but fluctuations in the local value of the electroweak Higgs field, which is a scalar field that represents the average energy of a fermionic spacetime point, imputing an energy of approximately the Planck energy for a stationary point (0 point), and zero for a speed-of-light point (c point). The fluctuations occur as spacetime seeks the vacuum expectation value v of the Higgs field by changing stationary points to speed-of-light points and vice versa, thereby ensuring that the ratio of speed-of-light points to stationary points is approximately E_{Pl}/v, where E_{Pl} is the Planck energy.

The vacuum expectation value v represents the average energy of a point when the Higgs field is at the minimum of its potential energy. It reveals the ratio of 0 (stationary) points to c (velocity of light) points. It is uniform throughout spacetime to an extraordinary degree. For example, every electron, no matter where or when it is observed, has exactly the same mass within experimental accuracy.

Spacetime is like a plasma of negative charges embedded in a sea of positive charges. In spacetime, stationary points are embedded in a sea of velocity-of-light points. Just as a plasma acts to equalize the distribution of negative charges, spacetime acts to equalize the distribution of 0 points to maintain the value of v. If there are too many stationary points in a local area, so that $\phi_3 > v$, interactions between points occur that change 0 points to c points, and conversely. Such excesses and deficiencies can occur in the forward-time spacetime, the backward-time spacetime, or both.

Such fluctuations occur constantly, but we do not see them unless there are particles involved. When a 0 point changes to a c point and a particle is present, we see, for example, an electron change to a neutrino. At another point, a matching pair of particles is created: an electron and an antineutrino. Thus, the excess 0 point at one location is moved to another location that had a deficiency of 0 points. These interactions *between particles* are seen as an exchange of $W^{\pm}$ bosons.

In the inflaton spacetime model, the average distance between fermionic spacetime points after inflation is approximately the Planck length. We've also estimated that there are about 10^{17} c points for every 0 point. For a rough estimate of the density of 0 points, let's assume that each point, 0 or c, occupies a volume equal to the cube of the Planck length, about 10^{-33} cm. Then there is one 0 point for every 10^{17} point volumes, or approximately $10^{17}(10^{-33})^3 = 10^{-82}$ cm^3. Thus, there are about 10^{82} 0 points per cm^3! In other words, there could be a deficiency or an excess of millions of 0 points in a very small volume of space and the percentage change in the vacuum expectation value of the Higgs field would be so small as to make the fluctuation unobservable! The bigger the volume of space, the less likely it is that any variation in v will be detectable, but even at subnuclear scales, say in a volume of $(10^{-15}$ cm$)^3$, there are 10^{37} 0 points on average, and an excess or deficiency of, say, 10^7 points is only a variation in v of 10^{-28} GeV. Our conclusion, then, is that the vacuum expectation value of the Higgs fiend is essentially independent of when, where, or over what volume it is measured. The fluctuations of the Higgs field are exceedingly small in amplitude. It therefore seems that Higgs bosons are exceedingly scarce, so scarce as to make it highly unlikely that the LHC will see them above the background processes.

What can we say about the Higgs mass? Since we don't know the shape of the potential energy, we can only make a very rough estimate. Just because it seems reasonable to me, let's assume the potential is triangular, that is $V(\phi_3) = A\phi_3$, where A is some constant, and there is an infinite barrier at $\phi_3 = 0$. The wave function for the field is then proportional to the Airy function. The first energy level, which represents the expectation value plus the Higgs mass, is proportional to the first zero of this function, or -2.338. We can't calculate the energy directly, since we don't know what A is, but if we can find a similar number for the expectation value, which we know is 246 GeV, we can use a simple ratio to estimate the energy. The mean value for this wave function differs from the first zero by 1.57. Dividing 2.338 by 1.57 and multiplying by 246, we get a value for the minimum energy of 366 GeV. Thus, we can speculate that the Higgs mass might be somewhere in the neighborhood of 366 - 246 = 120 GeV. Both the LHC and the Tevatron are capable of exploring this region, but as we have seen, it is unlikely that there are many Higgs bosons to be found.

Electron Mass

A massive fermion, an electron in this note, is an excited state of a point that is stationary part of the time, so that it moves at less than the speed of light. Its energy, and therefore its mass, is determined by the precision with which its location can be determined. In other words, its mass is simply the inverse of the uncertainty of its position, or equivalently, the inverse of its Compton wavelength. If all points were stationary, any point could be located within the Planck length and an electron would have a mass on the order of the Planck mass. All points are not stationary in this model, so even if a point could be located within the Planck length, an electron would have a mass of only 246 GeV. Moreover, we can't locate stationary points so precisely, since all we know is that there is one stationary point for each 10^{17} moving points. Therefore, the mass of the electron is even smaller.

How much smaller? The vacuum expectation value of the Higgs field, v, tells us that there is only one stationary point for about 10^{17} relativistic points. This implies two things: first, the average energy per arbitrary point is 246 GeV, and second, the energy of each stationary point is spread over a volume of about 10^{17} point wells. Since we don't know where in this volume the stationary point is located, by the uncertainty principle the effective energy of a stationary point, 246 GeV, is reduced by the ratio of the radius of one point well (the Planck length) to the radius of a volume containing 10^{17} point wells. The radius of a spherical well is proportional to the cube root of its volume, so the reduction factor is the cube root of the ratio of the volume of one point well to the volume of 10^{17} point wells. This works out to be the cube root of the ratio of the vacuum expectation energy to the original point energy, about twice the Planck energy. The result of this calculation is an electron mass of 0.513 MeV, almost exactly the experimental value.

W Boson Mass

For both fermions and bosons, mass is the inverse of the Compton wavelength, but we arrive at estimates of the Compton wavelength in different ways. For the W boson, a gauge boson, we will try to estimate the range of the particle. We will consider electron-neutrino scattering, a charged-current weak interaction. In the Feynman diagram of this interaction, we see an electron and a neutrino appear to change identities, exchanging a W boson. How far does the W boson have to travel, on average, in such an interaction? Let's say a neutrino turns into an electron. In this model, this means that a moving point has changed to a stationary point. To complete the interaction, a stationary point must be found to change into a moving point. What is the expected value of the distance to the nearest stationary point, given that there is one stationary point for every 10^{17} points? We are looking for the distance from a random starting point to the first stationary spacetime point in a given direction. A reasonable guess is that the distance has a Gaussian distribution around the starting point, the standard deviation or average distance to the first stationary point being 1/v in natural units. One standard deviation would be equal to the range, or Compton wavelength, of a particle with a mass equal to v, but there is a high probability that the interaction cannot be completed within this distance, so the W range is probably larger. Three standard deviations give almost 100% probability that the interaction will be completed. If we then estimate the expected range or Compton wavelength of the W boson as three standard deviations, our estimate of m_W is v/3 = 246/3 = 82 GeV, very close to the measured value.

Discussion

What can we learn from the simple discrete model presented in this note? First, the rest mass or inertial mass of the electron represents nothing more than the uncertainty in the position of an electron at rest (or the certainty, depending on whether your glass is half empty or half full). This uncertainty is determined by the vacuum expectation value of the Higgs field. It does make sense that inertia, or resistance to acceleration, is simply the property of having a finite position uncertainty. If an object has no resistance to acceleration, it can move anywhere with no provocation, so its position uncertainty is infinite, like a massless particle. Conversely, if it has a finite position uncertainty, it must have inertia.

Second, the masses of the W and Higgs bosons are determined entirely by their ranges. These are limited because the vacuum expectation value of the Higgs field is not zero. Therefore, these bosons are massive.