The Prediction and Evidence for a New Particle - antiparticle Force and Intermediary Particle

B.G. Sidharth
International Institute for Applicable Mathematics & Information Sciences
Hyderabad (India) & Udine (Italy)
B.M. Birla Science Centre, Adarsh Nagar, Hyderabad - 500 063 (India)

Abstract

We review some recent studies of particle-antiparticle behaviour (including proton-antiproton) at high energies, which suggest a new short lived interaction between them. We then examine the latest evidence from the CDF team at Fermi Lab which bears out this result to a little above 3σ level.

1 Introduction

The supposedly unphysical negative energy solutions appear in relativistic Quantum Mechanics, whether it be in the Klein-Gordon or the Dirac equation. For the Klein-Gordon equation it was immediately recognized that the second time derivative gives an extra degree of freedom in the form of the negative energy solutions. These extra solutions were interpreted by Pauli and Weisskopf in a Quantum Field theoretical sense [1]. There was an approach by Feshbach and Villars [2] in terms of a two component Klein-Gordon equation, in which they retained a particle sense. In this case it turned out that the negative solutions would represent anti particles. Dirac tried to circumvent these difficulties by invoking an equation that was first order in the time derivative, although at the expense of introducing ultimately four component wave functions [3]. In spite of this, the negative
energy electron problem remained and Dirac had to introduce the negative energy sea which was ostensibly filled up, while a positive energy electron could not transit into the sea by virtue of the Pauli Exclusion Principle. In this case an empty negative energy electron state or hole would appear as a Positron. All this is well known.

2 Negative Energy States

We first make a few comments: Only the positive energy states alone do not form a complete set for the Klein-Gordon or Dirac equations. For localization a particle would have to be represented by a wave packet consisting of both positive energy and negative energy solutions. The minimum extension of such a localized packet is of the order of the Compton wavelength (Cf.ref.[2]). This means that at energies which are high enough that we are near the Compton wavelength, we begin to encounter negative energies. It must be emphasized that the Dirac electron itself has the velocity \( c \). Dirac himself explained that this is the case if we carry over in a straightforward manner the concept of spacetime points [3]. He emphasized that our physical measurements are averages over spacetime intervals. In fact Wigner and Salecker have argued that usual spacetime points are invalid within the Compton scale [4]. Within the Compton scale we encounter unphysical phenomena like negative energy solutions and Zitterbewegung [5].

In the case of the Dirac equation, we can form meaningful probability currents and sub luminal velocities using positive energy solutions alone as long as we are outside the Compton wavelength [6]. However as we approach the Compton scale we begin to encounter negative energy solutions, or in the Feshbach- Villars description, anti particles.

To proceed, let us write the Dirac wave function as

\[
\psi = \begin{pmatrix} \phi \\ \chi \end{pmatrix},
\]

where \( \phi \) and \( \chi \) are each two spinors. As is well known [6], we can then deduce

\[
\hbar \left( \frac{\partial \phi}{\partial t} \right) = c \tau \cdot \left( p - \frac{e}{cA} \right) \chi + (mc^2 + e\phi)\phi,
\]

\[
\hbar \left( \frac{\partial \chi}{\partial t} \right) = c \tau \cdot \left( p - \frac{e}{cA} \right) \phi + (-mc^2 + e\phi)\chi.
\] (2)

We recapitulate that at low energies \( \chi \) is small and \( \phi \) dominates, whereas it is the reverse at high energies. We also note that while sensible wave packets
can be formed with the positive energy solutions alone, in general we require both signs of energy for a localized particle. In fact the Compton wavelength is the minimum extension, below which both positive and negative solutions will have to be considered. Well outside the Compton wavelength, we can continue with the usual positive energy description. More formally the positive energy solutions alone do not form a complete set of eigen functions of the Hamiltonion.

The following symmetry can be seen from (2) (with \( e = 0 \), or the absence of an external electromagnetic field for simplicity):

\[
t \rightarrow -t, \phi \rightarrow -\chi
\]  

(3)

We must remember that we are now dealing with intervals at the Compton scale, so that the negative energy solutions are relevant. So the time reversal given in (3) is at the Compton scale.

It has been pointed out by the author that this flip flop in time in the microscopic interval \((t \rightarrow -t)\) can be modelled by a Double Weiner process \([7, 8]\). It is related to Zitterbewegung (Cf.ref.[5]).

It is quite remarkable that in the case of the Klein-Gordon equation too, we get back equations identical to (2), but this time the wave functions have slightly different meaning. To see this in a little greater detail, we look for an appropriate \(\Psi\) such that \(\Psi\) satisfies the Hamiltonian form for the wave equation:

\[
H\Psi = \hat{h}(\partial \Psi / \partial t).
\]  

(4)

To obtain this form it is necessary to resolve \(\Psi\) into the components representing the two degrees of freedom implied by the Klein-Gordon equation: \(\phi\) and \(\chi\). The function \(\Psi\) is then a unicolumn matrix formed from these two components identical to (1).

The obvious first step in such a development is to introduce \(\partial \psi / \partial t\) as an independent component. Let (Cf.ref.[2])

\[
\psi_4 = -k^{-1}D_4\psi.
\]  

(5)

Then the Klein-Gordon equation may be written in an equivalent form equivalent to as follows:

\[
D_4\psi + k\psi_4 = 0,
\]

\[
\sum_k D_k^2\psi - kD_4\psi_4 - k^2\psi = 0.
\]  

(6)
where $D_\mu$ is the derivative with respect to the $\mu$th coordinate. These equations are already in the Hamiltonian form (4), but the combination $\psi$ and $\psi_4$ does not prove to be convenient because of the asymmetry of (6). Accordingly, we introduce the linear combination,

$$
\psi = 1/\sqrt{2}(\phi + \chi),
$$

$$
\psi_4 = 1/\sqrt{2}(\phi - \chi).
$$

The equations for $\phi$ and $\chi$ are

$$
D_4\phi = (1/2k) \sum_k D_k^2(\phi + \chi) - k\phi,
$$

$$
D_4\chi = (1/2k) \sum_k D_k^2(\phi + \chi) + k\chi
$$

(8)

which may be written more explicitly as

$$
\hbar(\partial \phi/\partial t) = (1/2m)(\hbar/i\nabla - eA/c)^2(\phi + \chi)
$$

$$
+ (e\phi + mc^2)\phi
$$

$$
\hbar(\partial \chi/\partial t) = -(1/2m)(\hbar/i\nabla - eA/c)^2(\phi + \chi)
$$

$$
+ (e\phi - mc^2)\chi
$$

(9)

very similar to [2] of the Dirac case, except that in this case $\phi$ and $\chi$ are scalar functions, rather than 2 spinors as in the Dirac case.

### 3 A New Interaction

To proceed further we observe the the two Weiner process referred to above, that is ($t \rightarrow -t$) can be described by the following equation

$$
\frac{d_+}{dt}x(t) = b_+, \quad \frac{d_-}{dt}x(t) = b_-
$$

(10)

where we are for the moment in the one dimensional case. This equation (10) expresses the fact that the right derivative with respect to time is not necessarily equal to the left derivative. It is well known that (10) leads to the Fokker Planck equations [7, 8]

$$
\partial \rho/\partial t + \text{div}(\rho b_+) = V \Delta \rho,
$$

where $\rho$ is the density function.
\[
\frac{\partial \rho}{\partial t} + \text{div}(\rho \mathbf{b}_-) = -U \Delta \rho
\]  
(11)

-defining
\[
V = \frac{\mathbf{b}_+ + \mathbf{b}_-}{2}; U = \frac{\mathbf{b}_+ - \mathbf{b}_-}{2}
\]  
(12)

We get on addition and subtraction of the equations in (11) the equations
\[
\frac{\partial \rho}{\partial t} + \text{div}(\rho V) = 0
\]  
(13)
\[
U = \nu \nabla \ln \rho
\]  
(14)

It must be mentioned that \(V\) and \(U\) are the statistical averages of the respective velocities and their differences. We can then introduce the definitions
\[
V = 2\nu \nabla S
\]  
(15)
\[
V - iU = -2\nu \nabla (\ln \psi)
\]  
(16)

We will not pursue this line of thought here but refer the reader to Smolin [9] for further details. We now observe that the complex velocity in (16) can be described in terms of a positive or unidirectional time \(t\) only, but a complex coordinate
\[
x \to x + ix'
\]  
(17)

To see this let us rewrite (12) as
\[
\frac{dX_r}{dt} = V, \quad \frac{dX_i}{dt} = U,
\]  
(18)

where we have introduced a complex coordinate \(X\) with real and imaginary parts \(X_r\) and \(X_i\), while at the same time using derivatives with respect to time as in conventional theory.

From (12) and (18) it follows that
\[
W = \frac{d}{dt}(X_r - iX_i)
\]  
(19)

This shows that we can use derivatives with respect to the usual time derivative with the complex space coordinates (17) (Cf.ref.10).

Generalizing (17), to three dimensions, we end up with not three but four dimensions,
\[
(1, i) \to (I, \tau),
\]
where $I$ is the unit $2 \times 2$ matrix and $\tau$s are the Pauli matrices. We get the special relativistic Lorentz invariant metric at the same time. That is,

$$x + iy \to Ix_1 + ix_2 + jx_3 + kx_4,$$

where $(i, j, k)$ momentarily represent the Pauli matrices; and, further,

$$x_1^2 + x_2^2 + x_3^2 - x_4^2$$

is invariant.

The right hand side of (20) in terms of Pauli matrices, obeys the quaternionic algebra of the second rank spinors (Cf. Ref. [10, 11, 12] for details).

To put it briefly, the quaternion number field obeys the group property and this leads to a number system of quadruplets as a minimum extension.

In fact one representation of the two dimensional form of the quaternion basis elements is the set of Pauli matrices above. Thus a quaternion may be expressed in the form

$$Q = -i\tau_\mu x^\mu = \tau_0 x^4 - \tau_1 x^1 - \tau_2 x^2 - \tau_3 x^3 = (\tau_0 x^4 + i\vec{r} \cdot \vec{r})$$

This can also be written as

$$Q = -i \begin{pmatrix} i(x^4 + x^3) & x^1 - i x^2 \\ x^1 + i x^2 & i x^4 - x^3 \end{pmatrix}.$$ 

As can be seen from the above, there is a one to one correspondence between a Minkowski four-vector and $Q$. The invariant is now given by $\overline{Q}Q$, where $\overline{Q}$ is the complex conjugate of $Q$.

In this description we would have from (20), returning to the usual notation,

$$[x^i \tau^i, x^j \tau^j] \propto \epsilon_{ijk} \tau^k \neq 0$$

(No summation over $i$ or $j$)

Equation (22) shows that the coordinates no longer follow a commutative geometry. It is quite remarkable that the noncommutative geometry (22) has been studied by the author in some detail (Cf. [7]), though from the point of view of Snyder's minimum fundamental length, which he introduced to overcome divergence difficulties in Quantum Field Theory. Indeed we are essentially in the same situation, because as we have seen, for our positive
energy description of the universe, there is the minimum Compton wavelength cut off for a meaningful description [13, 14, 15]. Proceeding further we could think along the lines of $SU(2)$ and consider the gauge transformation [16]

$$\psi(x) \to \exp\left[\frac{1}{2}ig\tau \cdot \omega(x)\right]\psi(x).$$  \hspace{1cm} \text{(23)}

This leads as is well known to a gauge covariant derivative

$$D_\lambda \equiv \partial_\lambda - \frac{1}{2}ig\tau \cdot \bar{W}_\lambda,$$  \hspace{1cm} \text{(24)}

where $\omega$ in this theory is infinitesimal. We are thus led to vector Bosons $\bar{W}_\lambda$ and an interaction like the strong interaction, described by

$$\bar{W}_\lambda \to \bar{W}_\lambda + \partial_\lambda \omega - g\omega \Lambda \bar{W}_\lambda.$$  \hspace{1cm} \text{(25)}

However, we are this time dealing, not with iso spin, but between positive and negative energy states as in (1) that is particles and antiparticles. Also we must bear in mind that this non-electromagnetic force between particles and anti particles would be short lived as we are at the Compton scale [17]. These considerations are also valid for the Klein-Gordon equation in the two component notation developed by Feshbach and Villars [2, 18]. There too, we get equations like (2). We would like to re-emphasize that our usual description in terms of positive energy solutions is valid above the Compton scale.

Thus we are lead to a new short lived interaction (as we are near the Compton scale), mediated by vector Bosons $\bar{W}$.

With regard to the $\bar{W}$ acquiring mass, apart from the usual approach, we can note the following. Equation (22) underlines the non-commutativity of spacetime, and under these circumstances it has been argued that there is a break in symmetry that leads to a mass being acquired exactly as with the Higgs mechanism [19, 7].

4 Experimental Observation

It is quite remarkable that evidence for such a reaction has just been announced by the CDF team of Fermi Lab [20]. They report a study of the invariant mass distribution of jet pairs produced in association with a $W$
boson using data collected with the CDF detector which correspond to an integrated luminosity of $4.3fb^{-1}$. The observed distribution has an excess in the $120-160GeV/c^2$ mass range which is not described by current theoretical predictions within the statistical and systematic uncertainties. In this latter they report studies of the properties of this excess.

In fact what the authors, T. Aaltonen et al., have done is, they performed a statistical comparison of the measurements of associated production of $\bar{W}$ Boson and jets by including additional data and further studying $M_{jj}$ distribution for masses higher than $100GeV$, with minimal changes to the event selection with respect to the previous analysis. They found a statistically significant disagreement that the other theoretical predictions.

Their model describes the data within uncertainties, except in the mass region $\sim 120-160GeV$ where an excess over the simulation is seen. Briefly they have found evidence for a new Force and Particle, unrelated to known physics in the Proton $p-\bar{p}$ interactions. Their results are accurate to the above $3\sigma$ level. Further analysis is required to push the confidence levels to the $5\sigma$ level.

5 Remarks

As noted in Section 3, the non-commutativity (22) can generate mass. Let us see this in greater detail. The Gauge Bosons would be massless and hence the need for a symmetry breaking, mass generating mechanism.

The well known remedy for the above situation has been to consider, in analogy with superconductivity theory, an extra phase of a self coherent system (Cf.ref.[21] for a simple and elegant treatment and also refs. [22] and [16]). Thus instead of the gauge field $A_\mu$, we consider a new phase adjusted gauge field after the symmetry is broken

$$\bar{W}_\mu = A_\mu - \frac{1}{q}\partial_\mu \phi$$ (26)

The field $\bar{W}_\mu$ now generates the mass in a self consistent manner via a Higgs mechanism. Infact the kinetic energy term

$$\frac{1}{2}|D_\mu \phi|^2$$ (27)

where $D_\mu$ in (27) denotes the Gauge derivative, now becomes

$$|D_\mu \phi_0|^2 = q^2|\bar{W}_\mu|^2|\phi_0|^2,$$ (28)
Equation (28) gives the mass in terms of the ground state $\phi_0$.
The whole point is as follows: The symmetry breaking of the gauge field manifests itself only at short length scales signifying the fact that the field is mediated by particles with large mass. Further the internal symmetry space of the gauge field is broken by an external constraint: the wave function has an intrinsic relative phase factor which is a different function of spacetime coordinates compared to the phase change necessitated by the minimum coupling requirement for a free particle with the gauge potential. This cannot be achieved for an ordinary point like particle, but a new type of a physical system, like the self coherent system of superconductivity theory now interacts with the gauge field. The second or extra term in (26) is effectively an external field, though (28) manifests itself only in a relatively small spatial interval. The $\phi$ of the Higgs field in (26), in analogy with the phase function of Cooper pairs of superconductivity theory comes with a Landau-Ginzburg potential $V(\phi)$.

Let us now consider in the gauge field transformation, an additional phase term, $f(x)$, this being a scalar. In the usual theory such a term can always be gauged away in the U(1) electromagnetic group. However we now consider the new situation of a noncommutative geometry referred to above,

$$[dx^\mu, dx^\nu] = \Theta^{\mu\nu} \beta, \beta \sim 0(l^2)$$

(29)

where $l$ denotes the minimum spacetime cut off. Equation (29) is infact Lorentz covariant. Then the $f$ phase factor gives a contribution to the second order in coordinate differentials,

$$\frac{1}{2} [\partial_\mu B_\nu - \partial_\nu B_\mu] [dx^\mu, dx^\nu]$$

$$+ \frac{1}{2} [\partial_\mu B_\nu + \partial_\nu B_\mu] [dx^\mu dx^\nu + dx^\nu dx^\mu]$$

(30)

where $B_\mu \equiv \partial_\mu f$.

As can be seen from (30) and (29), the new contribution is in the term which contains the commutator of the coordinate differentials, and not in the symmetric second term. Effectively, remembering that $B_\mu$ arises from the scalar phase factor, and not from the non-Abelian gauge field, $A_\mu$ is replaced by

$$A_\mu \to A_\mu + B_\mu = A_\mu + \partial_\mu f$$

(31)

Comparing (31) with (26) we can immediately see that the effect of noncommutativity is precisely that of providing a new symmetry breaking term to
the gauge field, instead of the $\phi$ term, (Cf.refs. [23, 24]) a term not belonging to the gauge field itself.

On the other hand if we neglect in (29) terms $\sim l^2$, then there is no extra contribution coming from (30) or (31), so that we are in the usual non-Abelian gauge field theory, requiring a broken symmetry to obtain an equation like (31). This is not surprising because if we neglect the term $\sim l^2$ in (29) then we are back with the usual commutative theory and the usual Quantum Mechanics.

References

[1] Pauli, W and Weisskopf, V.F.. (1934). Helv.Phys.Acta 1, 709 (1934).

[2] Freshbach, H. and Villars, F. (1958). Rev.Mod.Phys. Vol.30, No.1, January 1958, pp.24-45.

[3] Dirac, P.A.M. (1958). The Principles of Quantum Mechanics (Clarendon Press, Oxford), pp.4ff, pp.253ff.

[4] Salecker, H. and Wigner, E.P. (1958). Quantum Limitations of the Measurement of Space-Time Distances Physical Review Vol.109, No.2, January 15 1958, pp.571-577.

[5] Sidharth, B.G. (2008). Int.J.Th.Phys. 48 (2), 2008, pp.497-506.

[6] Bjorken, J.D. and Drell, S.D. (1964). Relativistic Quantum Mechanics (Mc-Graw Hill, New York), pp.39.

[7] Sidharth, B.G. (2008). The Thermodynamic Universe (World Scientific), Singapore.

[8] Sidharth, B.G. (2011). Negative Energy Solutions and Symmetries, arXiv:1104.0116.

[9] Smolin, L. (1986). Quantum Concepts in Space and Time, Penrose, R. and Isham, C.J. (eds.) (OUP, Oxford), pp.147–181.

[10] Sidharth, B.G. (2003) Found.Phys.Lett. 16, (1), pp.91–97.

[11] Shirokov, Yu. M. (1958). Soviet Physics JETP 6, (33), No.5, pp.929–935.
[12] Sachs, M. (1982). *General Relativity and Matter* (D. Reidel Publishing Company, Holland), pp.45ff.

[13] Sidharth, B.G. (2002). *Foundation of Physics Letters* 15 (5), 2002, 501ff.

[14] S.S. Schweber. (1961). *An Introduction to Relativistic Quantum Field Theory* (Harper and Row, New York).

[15] Newton, T.D. and Wigner, E.P. (1949). *Reviews of Modern Physics* Vol.21, No.3, July 1949, pp.400-405.

[16] Taylor, J.C. (1976). *Gauge Theories of Weak Interactions* (Cambridge University Press, Cambridge) 1976.

[17] Sidharth, B.G. (2011). *Brief Report* in *New Advances in Physics* Vol.5 (1), 2011, pp.49-50.

[18] Sidharth, B.G. (2011) *Ultra High Energy Behaviour*, arXiv:1103.1496.

[19] Sidharth, B.G. (2005). *Int.J.Mod.Phys.E* 14 (6), 2005, pp.923ff.

[20] Aaltonen, T. et al. arXiv:1104.0699v1 in *hep-ex* 4 April 2011.

[21] Moriyasu, K. (1983). *An Elementary Primer for Gauge Theory* (World Scientific, Singapore, 1983).

[22] Greiner, W., and Muller, B. (2009). *Gauge Theory of Weak Interactions* (Springer, New York, 2009).

[23] Sidharth, B.G. (2004). *Proceedings of the Fifth International Symposium on Frontiers of Fundamental Physics* in (Universities Press, Hyderabad, 2004).

[24] Sidharth, B.G. (2005). *Int.J.Mod.Phys.E* 14 (2), 2005, p.215ff.