# Prediction of spin ½ Higgs-related particles, mass ~ $m_{Higgs}$

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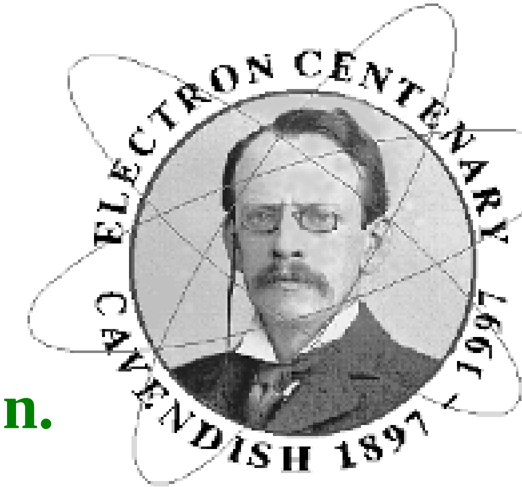
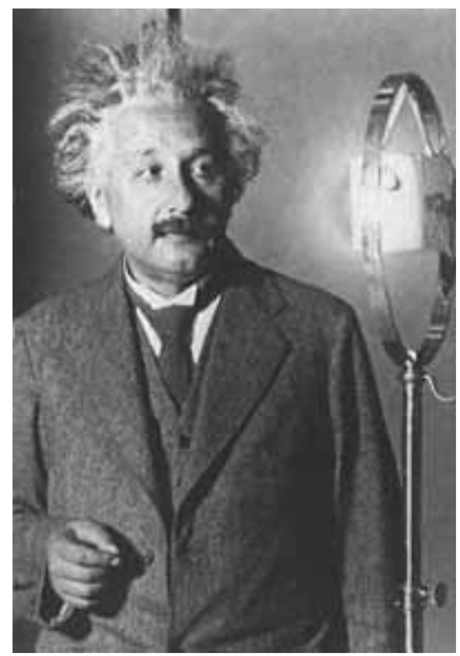



**The history of spin 1/2 fermions begins with the discovery of the electron in 1897 by J. J. Thomson.**

**The history of spin 1 gauge bosons begins with the 1905 paper of Einstein which introduced the photon.**

**A spin 0 boson is something new (2012), and surprises may *again* lie ahead!**



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**The LHC is back in action. What new discoveries lie ahead?**

In arXiv:1101.0586 [hep-th] the following Lagrangian is obtained for what would ordinarily be scalar boson fields:

$$\mathcal{L}_\Phi = \Phi_b^\dagger(x) D^\mu D_\mu \Phi_b(x) - \Phi_b^\dagger(x) S^{\mu\nu} F_{\mu\nu} \Phi_b(x)$$

where $D_\mu = \partial_\mu - i A_\mu^i t_i$ , $\Phi_b = \begin{pmatrix} \Phi_L \\ \Phi_R \end{pmatrix}$ , $F_{\mu\nu}$ is the field strength tensor,

$S^{\mu\nu} = \frac{1}{2}\sigma^{\mu\nu}$ consists of the Lorentz generators which act on Dirac spinors,

and $\Phi_L$ and $\Phi_R$ are 2-component Weyl spinors.

To regain standard physics, write each component $\Phi_b^r$ as $\phi_b^r \chi_b^r$ , where $\phi_b^r$ is a complex scalar and $\chi_b^r$ is a 4-component bispinor. If we add mass and self-interaction terms, and if the internal (spin) degrees of freedom are not excited (with $\chi_b^r$ normalized to unity), for the condensate described below we obtain the usual Lagrangian

$$\mathcal{L}_\Phi^r = \phi_b^{r\dagger} D^\mu D_\mu \phi_b^r - \mu^2 \phi_b^{r\dagger}\phi_b^r + \frac{1}{2}\left(\phi_b^{r\dagger}\phi_b^r\right)^2 \quad .$$

**So if these new internal degrees of freedom are not excited, the theory is Lorentz invariant. More generally (in the paper cited), we recover standard physics -- with the form of the standard model, plus *SO(N)* grand unification and supersymmetry.**

$$\mathcal{L}_\Phi = \Phi_b^\dagger(x) D^\mu D_\mu \Phi_b(x) - \Phi_b^\dagger(x) S^{\mu\nu} F_{\mu\nu} \Phi_b(x) \quad , \quad \Phi_b = \begin{pmatrix} \Phi_L \\ \Phi_R \end{pmatrix}$$

**The full Lagrangian is not Lorentz invariant (and this is presumably why nothing like this has been proposed by any of thousands of theorists over the past half century). But the Lorentz-violating aspect should show up only when energies are available for exciting the new Higgs-related excitations discussed below.**

**Note that this Lagrangian is not *ad hoc*. It is instead an unavoidable consequence of the broad theory. In fact, the theory of arXiv:1101.0586 [hep-th] leads to a number of unavoidable predictions:**

**Supersymmetry -- the theory cannot possibly be formulated without supersymmetry**

**SO(N) grand unification – the theory cannot be formulated without grand unification, or with any gauge group other than SO(N)**

**Spin ½ bosons – associated with the breaking of Lorentz invariance**

**Two historical precedents:**

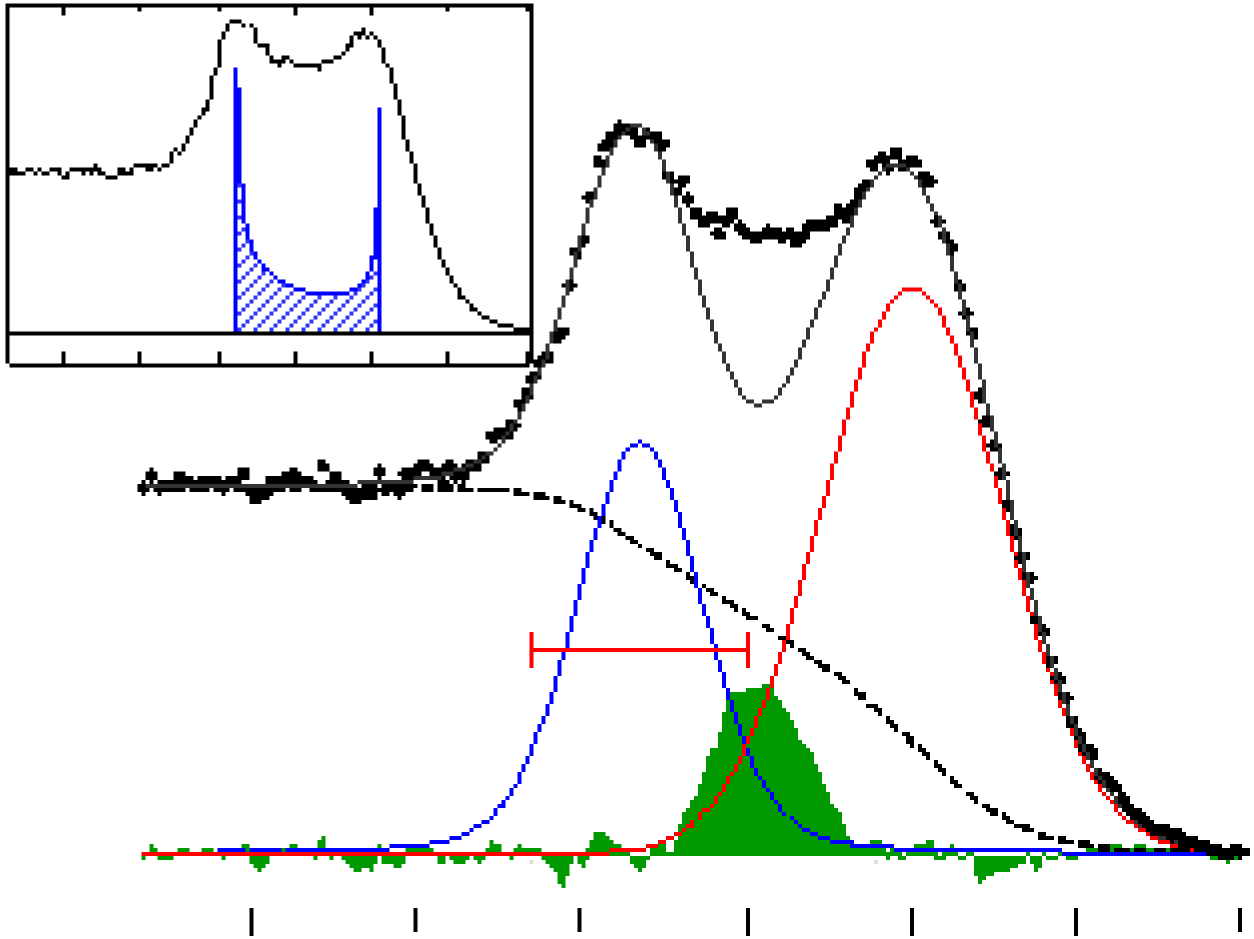
**(1) Again, after the electron was discovered in 1897, and the photon was introduced by Einstein in 1905, the richness of behavior associated with spin 1/2 fermions and spin 1 gauge bosons emerged slowly during the following decades. More than a century later, the third kind of Standard Model particle, with spin 0, has finally been discovered, and one should not be completely surprised if some of its implications are yet to be determined.**

**(2) Similarly, it should not be completely surprising if Lorentz invariance, like P and CP invariance, is found to be violated by some features of a more nearly complete theory (left-handed weak-interaction coupling, 3-generation Yukawa couplings, and here the internal degrees of freedom of would-be scalar bosons).**

**How might these previously hidden spin ½ degrees of freedom show up experimentally? With**

$$F_b^r = f_b^r \, c_b^r$$

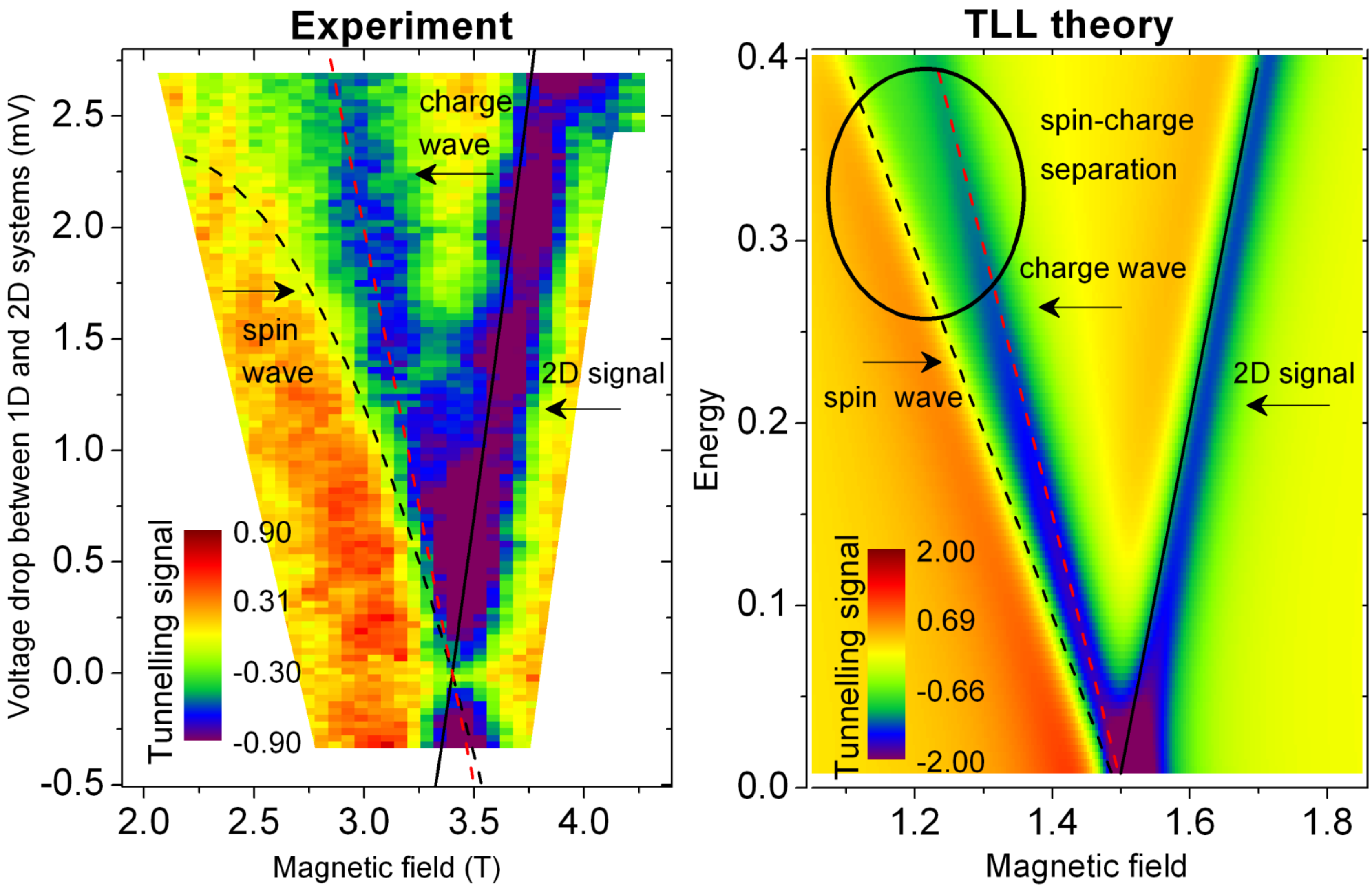
**one might expect the possibility of separation of charge and spin (or helicity/chirality) degrees of freedom, as in effectively 1-dimensional systems in condensed matter physics – i.e. chargons and spinons.**



**Angle-resolved photoemission spectroscopy study of $SrCuO_2$, at Lawrence Berkeley National Laboratory (2006), reveal two discrete peaks -- blue for holon and red for spinon -- demonstrating spin-charge separation.**

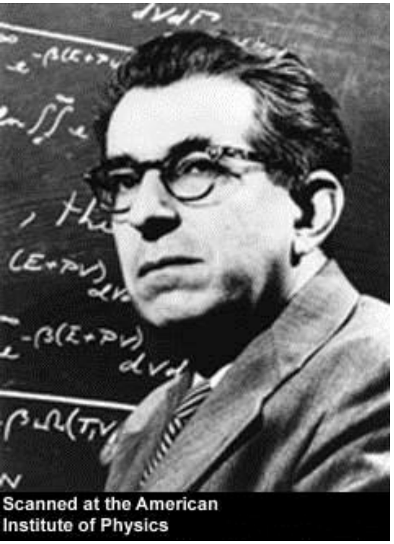
Credit: www2.lbl.gov/Science-Articles/Archive/ALS-spinons-holons.html

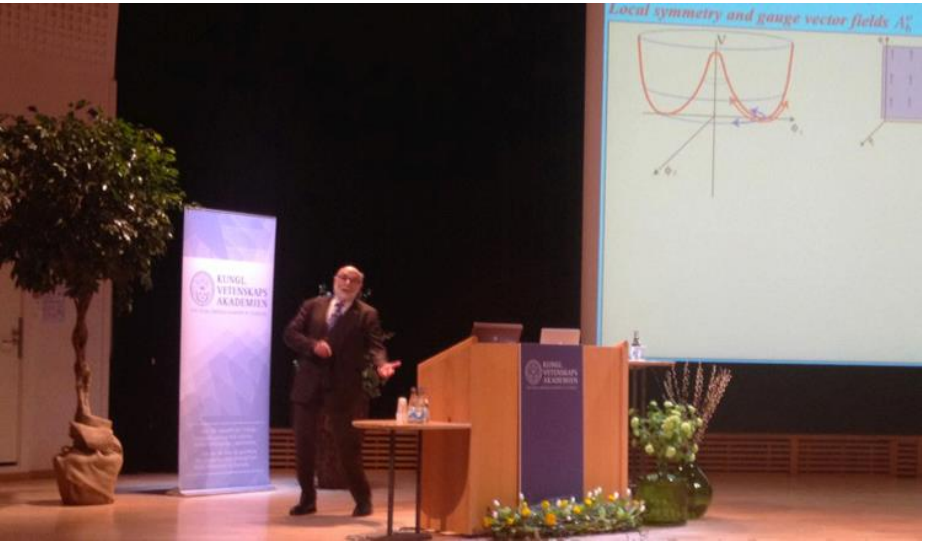
## Spin-charge separation in quantum wires: holons and spinons travel at different speeds




Credit: www.sp.phy.cam.ac.uk/research/1d-transport/SCseparation -- University of Cambridge, Cavendish Laboratory -- *Science* **325**, 597 (2009)

**However, a much better analogy appears to be s-wave superconductors. The superconductor version of the Higgs field dates back to the 1935 paper of Fritz and Heinz London (with the condensate effectively giving mass to the photon) and the 1963 paper of Phil Anderson (which apparently inspired the 1964 papers of Englert and Brout, of Higgs, and of Guralnik, Hagen, and Kibble).**




**For superconductors there have been several theoretical treatments of and experimental observations of the "Higgs mode" – which corresponds to the Higgs boson (as opposed to the condensate of superconducting electrons, which corresponds to the Higgs condensate).**

**The Higgs mode has an effective mass of 2 Δ, where Δ is the gap parameter.**

**It thus has the same effective mass as an electron quasiparticle which is excited across the energy gap of 2 Δ.**

**The spin ½ particles considered here are analogous to electron quasiparticles – and we will in fact call them quasiparticles – so we take this result to indicate that $m_{\mathrm{qp}} \sim m_{Higgs}$ for the quasiparticles associated with a Higgs condensate.**

**However, the analogy is not perfect, because the present quasiparticles are spin ½ bosons rather than fermions. Also, their fields are not paired as in a superconductor, but instead are grouped together in a bispinor with left and right chiral parts.**

A better model: $\mathcal{L}_\Phi^r = \Phi_b^{r\dagger} D^\mu D_\mu \Phi_b^r - \mu^2 \Phi_b^{r\dagger}\Phi_b^r + \frac{1}{2}\left(\Phi_b^{r\dagger}\Phi_b^r\right)^2$

In the condensate $\Phi_L = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$, $\Phi_R = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ so the vacuum has zero angular momentum, and the $\Phi_b^\dagger(x) S^{\mu\nu} F_{\mu\nu} \Phi_b(x)$ term also has zero vacuum expectation value when all the condensed fields have this form.

If the "hidden" internal degrees of freedom are not excited, the standard treatment yields the mass of a Higgs boson:

$$\mathcal{L}_v = -\mu^2 (v+h)^2 + \frac{1}{2}\lambda (v+h)^4 \quad , \quad v^2 = \frac{\mu^2}{\lambda}$$

$$= 2\mu^2 h^2 + \text{ the } h^3 \text{ and } h^4 \text{ terms}$$

where $v$ is the vacuum expectation value and $h$ is the excitation, so the Higgs mass is $\sqrt{2}\,\mu$ .

But the same calculation for a left-handed spin 1/2 bosonic quasiparticle gives

$$\mathcal{L}_\ell = -\mu^2 \left[ (v_L + h_L)^2 + v_R^2 \right] + \frac{1}{2}\lambda \left[ (v_L + h_L)^2 + v_R^2 \right]^2 \quad , \quad v_L^2 = v_R^2 = \frac{1}{2}\frac{\mu^2}{\lambda}$$

$$= \mu^2 h_L^2 + \text{ the } h_L^3 \text{ and } h_L^4 \text{ terms}$$

so the mass of a quasiparticle $h_L$ is $\mu$ rather than $\sqrt{2}\,\mu$ . The same is true for $h_R$ .

The full Lagrangian automatically has supersymmetry before the internal degrees of freedom are excited, with auxiliary fields in $\mathcal{F}_b(x)$:

$$\mathcal{L}_f + \mathcal{L}_{sb} = \left[ \psi_f^\dagger(x) i \sigma^\mu D_\mu \psi_f(x) - \left( D^\mu \Phi_b(x) \right)^\dagger D_\mu \Phi_b(x) - \Phi_b^\dagger(x) S^{\mu\nu} F_{\mu\nu} \Phi_b(x) + \mathcal{F}_b^\dagger(x) \mathcal{F}_b(x) \right]$$

But with $F_b = \begin{pmatrix} F_L \\ F_R \end{pmatrix}$ and $D_m = \partial_m - i A^i_m t_i$ , one can read off the vertices in the Feynman diagrams for production and decay of these proposed new particles. From the term involving $D_m$ they can be produced somewhat like Higgs bosons, except in pairs. (In the simplest model, a quasiparticle has half the Yukawa coupling of a Higgs boson, and this is consistent with the treatment of Yukawa couplings in the broader theory.)

From the next term, involving the field strength tensor $F_m$ , a pair of these spin 1/2 bosonic quasiparticles can be produced from e.g. the decay of a virtual $Z^0$.

Such a Higgs-related quasiparticle should have a mass $m_{\mathrm{qp}} \sim m_{\mathrm{Higgs}}$ on general grounds. A simple model predicts $m_{\mathrm{qp}} = \dfrac{m_{\mathrm{Higgs}}}{\sqrt{2}}$ .

**Now a detailed phenomenology is needed!**