Is multiple t´-quarks bound states possible due to Higgs exchange?

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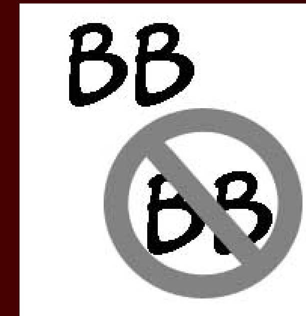
t´-balls: to be or not to be?



4-th generation is a natural extension of the Standard Model.

4-th generation quarks have hypothetical mass about several hundred GeV.

No bound states due to gluu--oon exchange (like charmonium or bottomonium)!

BUT! t´-quark – Higgs strong-coupling interaction

↓

Formation of t´-quarks – Higgs non-topological solitons (analogous to light chiral hadrons, not to heavy one)

- t´-quark – Higgs interaction

$$\mathcal{L}_b = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu,a} - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + (D_\mu\Phi)^\dagger(D^\mu\Phi) - \lambda(\Phi^\dagger\Phi - \frac{v^2}{2})^2$$

$$\mathcal{L}_f = \bar{\psi}_L i\gamma^\mu D_\mu \psi_L + \bar{u}_R i\gamma^\mu D_\mu u_R + \bar{d}_R i\gamma^\mu D_\mu d_R - f_U(\bar{\psi}_L\tilde{\Phi}u_R + \bar{u}_R\tilde{\Phi}^\dagger\psi_L) - f_D(\bar{\psi}_L\Phi d_R + \bar{d}_R\Phi^\dagger\psi_L)$$

$$\langle\Phi\rangle = -\frac{v}{\sqrt{2}}\begin{pmatrix}0\\1\end{pmatrix}$$

$$M_H = v\sqrt{2\lambda},$$

$$m_U = f_U\frac{v}{\sqrt{2}}, \qquad m_D = f_D\frac{v}{\sqrt{2}}.$$

t´-quark Yukawa coupling

$v = 246.0\text{GeV}$

$m_t = 176\text{GeV}$

$$f_t = 1.01 \times 10^{+0}$$

t´ coupling constant must be more than 1!

t´- balls physics: analogous to light chiral hadrons

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \pi_2 + i\pi_1 \\ \sigma - i\pi_0 \end{pmatrix}$$

$$\mathcal{L}_\sigma = \frac{1}{2}(\partial_\mu \sigma)^2 + \frac{1}{2}(\partial_\mu \pi)^2 + \bar{\psi}\gamma^\mu \partial_\mu \psi - g\bar{\psi}(\sigma + i\gamma_5 \pi \cdot \tau)\psi - U(\sigma, \pi)$$

$$U(\sigma, \pi) = \frac{\lambda}{2}\left[\sigma^2 + \pi^2 - v^2\right]^2$$

Analog of chiral quark lagrangian in TeV scale!

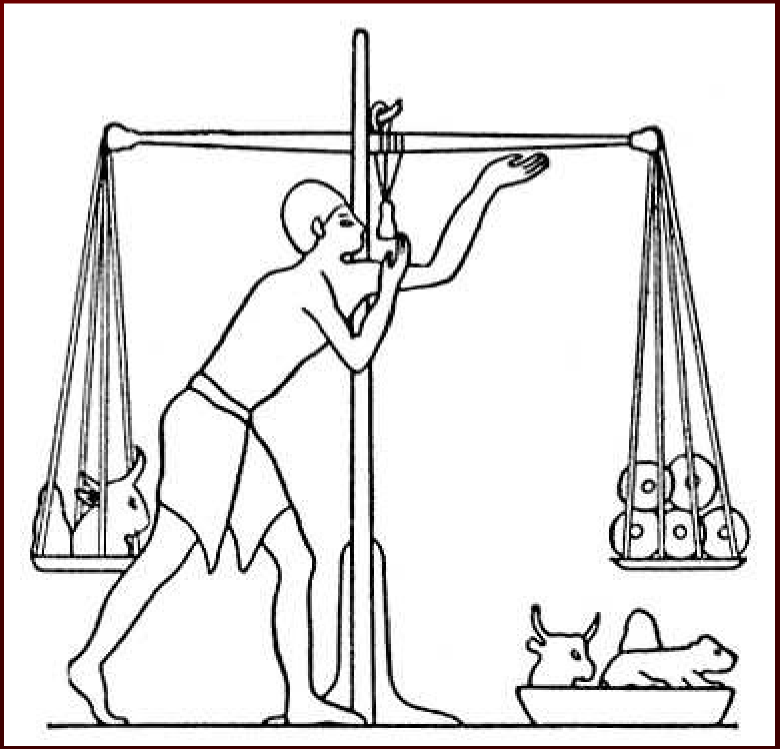
Main feature of strong coupling Fermion-Higgs system:

possibility of formation of the “Bubbles” in Higgs condensate!

If Fermion-Higgs interaction is strong enough

it is favorable for quasi-massless quarks to be inside

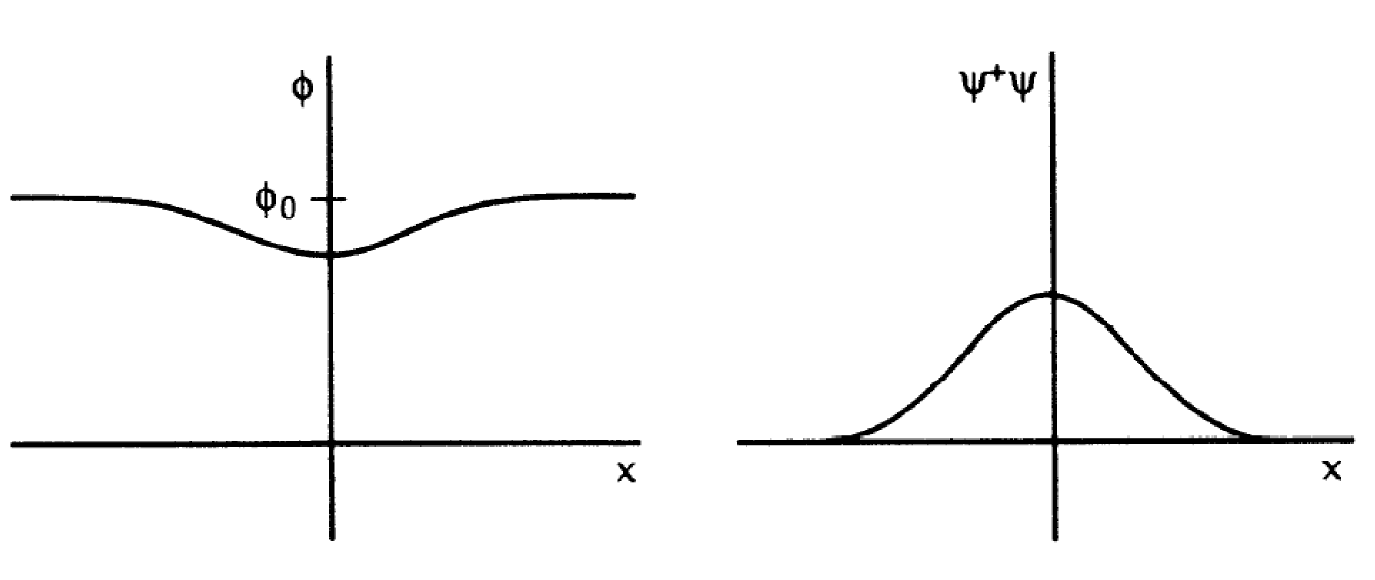
“bubble”-like soliton than to be free and massive.



One-dimensional illustration:

$$\mathcal{L} = \tfrac{1}{2}(\partial_\mu \phi)^2 - \frac{\lambda}{4}(\phi^2 - v^2)^2 + \bar{\psi}(i\partial\!\!\!/ - g\phi)\psi$$

$$\phi_k(x) = v \tanh \left[\frac{\lambda v^2}{2}\right]^{1/2} x$$



Three-dimensional case

$$\sigma(x) = \sigma(r), \quad \pi(x) = \pi(r)\hat{\mathbf{r}}$$

$$\psi(x) = \frac{1}{\sqrt{4\pi}} \begin{pmatrix} G(r) \\ i(\sigma \cdot \hat{\mathbf{r}})F(r) \end{pmatrix} \chi_h,$$

Spherically symmetrical field configurations

$$\frac{1}{r}\frac{d^2}{dr^2}[r\sigma(r)] = \frac{\partial U}{\partial \sigma} - \frac{g^2}{4\pi}[G^2(r) - F^2(r)],$$

$$\frac{1}{r}(\frac{d^2}{dr^2} - \frac{2}{r^2})[r\pi(r)] = \frac{\partial U}{\partial h} + \frac{g^2}{2\pi}G(r)F(r),$$

$$\frac{dF(r)}{dr} + [\frac{2}{r} - g\pi(r)]F(r) + [\omega + g\sigma(r)]G(r) = 0,$$

$$\frac{dG(r)}{dr} + g\pi(r)G(r) + [-\omega + g\sigma(r)]F(r) = 0.$$

Equations of motion

$$\int r^2 dr [F^2(r) + G^2(r)] = 1.$$

Normalization

How many fermions in “bubble” could be?

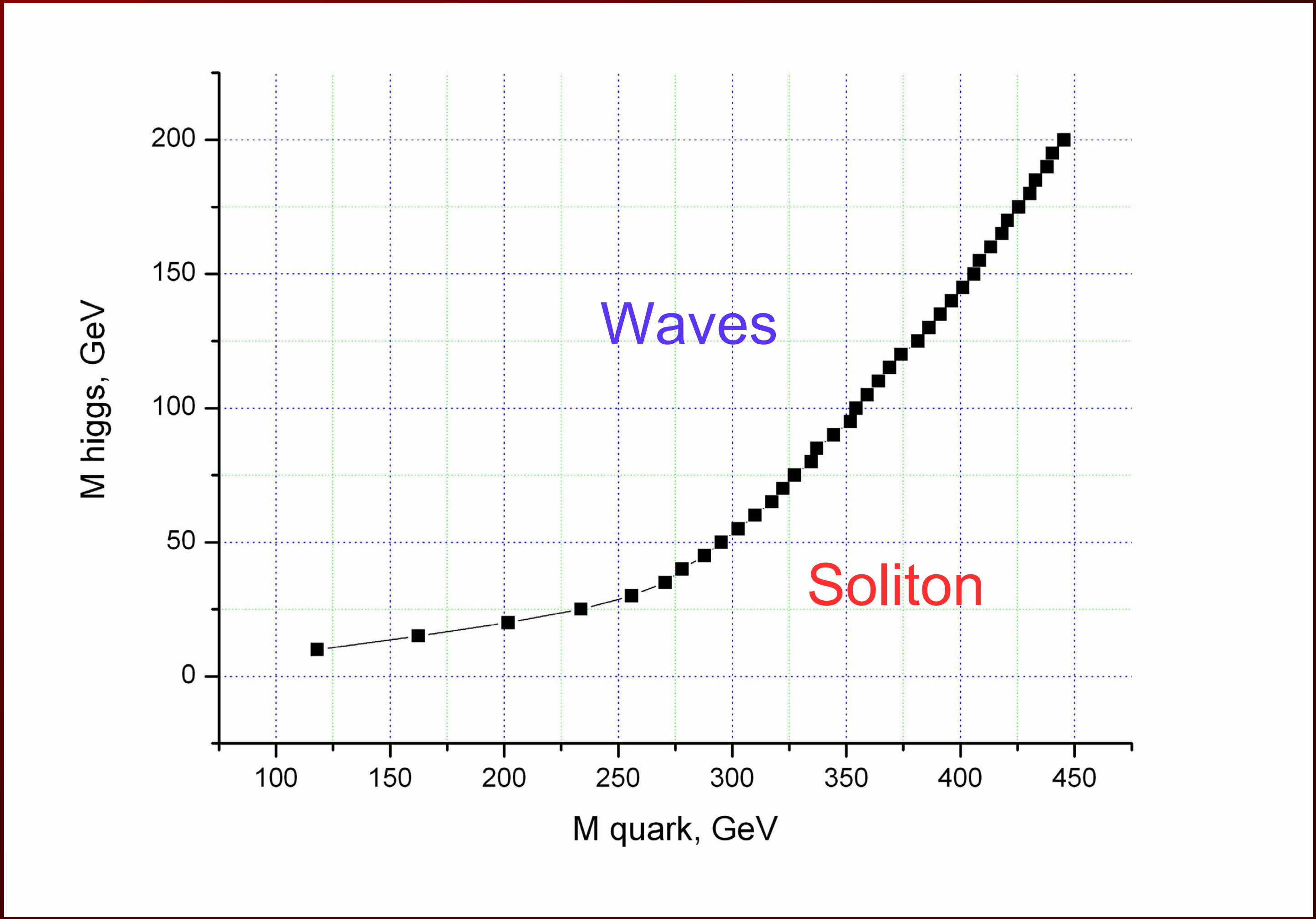
No soliton for one top-quark and for toponium!
Macpherson, Campbell, Phys.Lett.B306:379-385,1993.

For multi top-quark bound states it’s open question.

The more fermions one has in the “bubble”, the more such fermion-soliton system becomes energetically favorable.

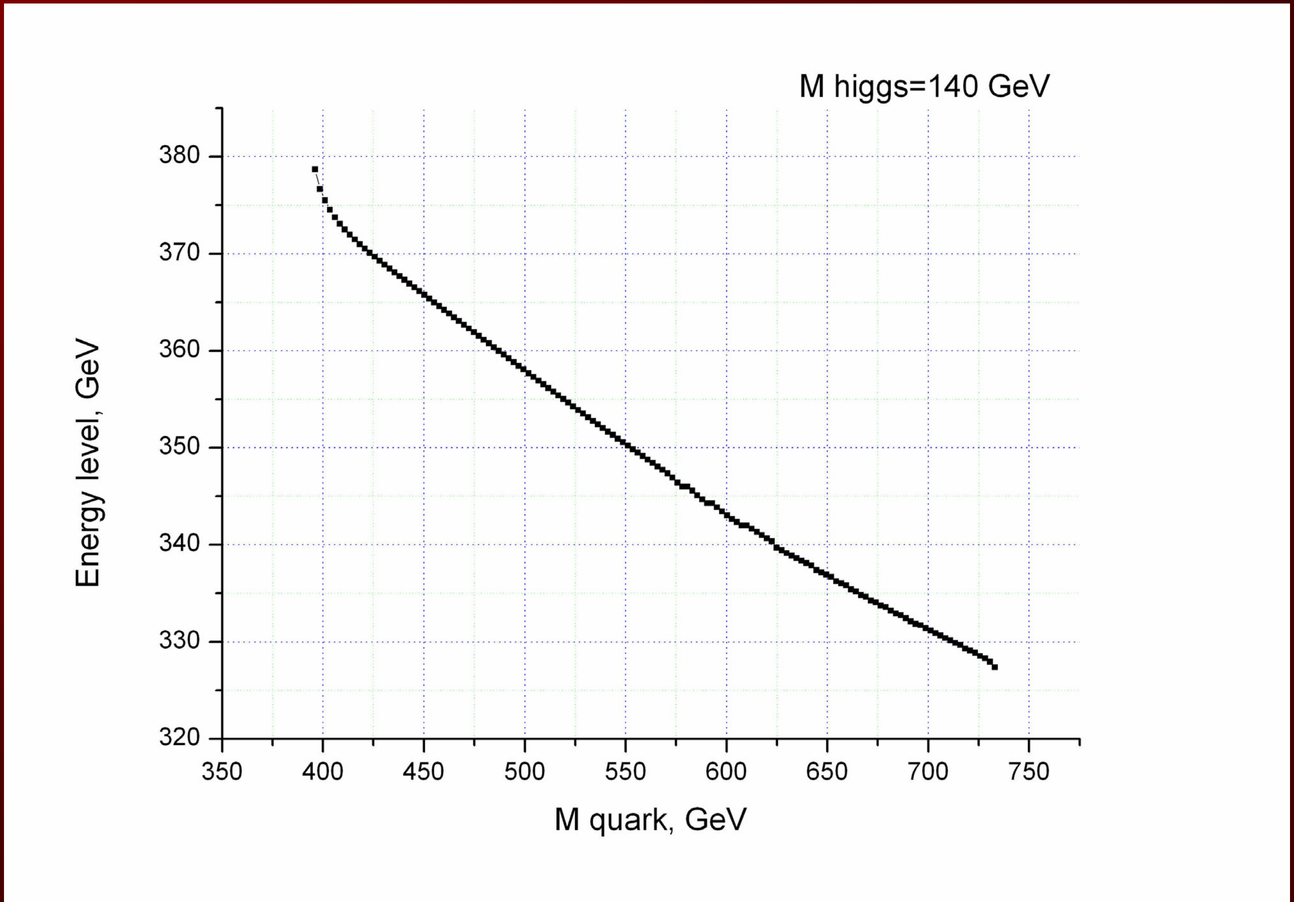
$$\frac{1}{r}\frac{d^2}{dr^2}[r\sigma(r)] = \frac{\partial U}{\partial \sigma} - \frac{g^2}{4\pi}\,\mathbf{N}\,[G^2(r) - F^2(r)]$$

Numerical results: soliton-waves phase diagram.



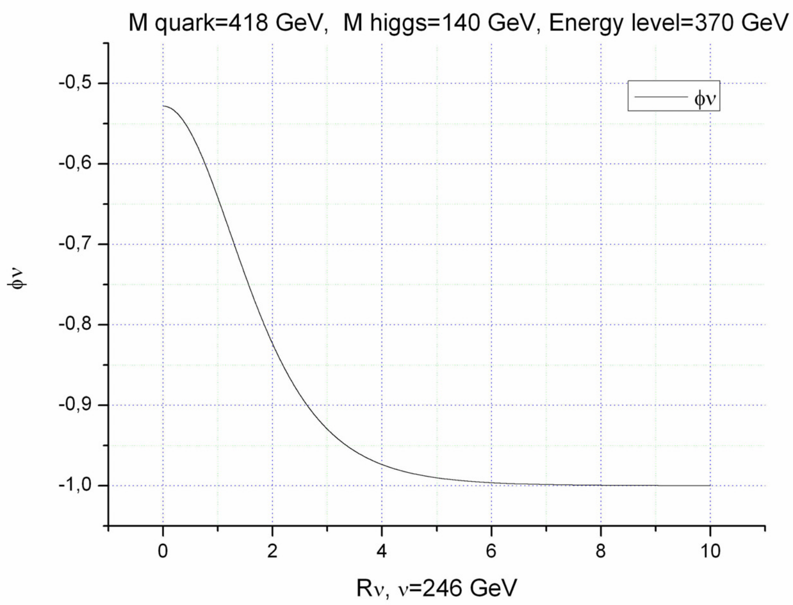
For Higgs mass around M(Higgs) = 140 GeV, soliton solution can be formed only for fermions with mass greater than M(t´) > 390 GeV.

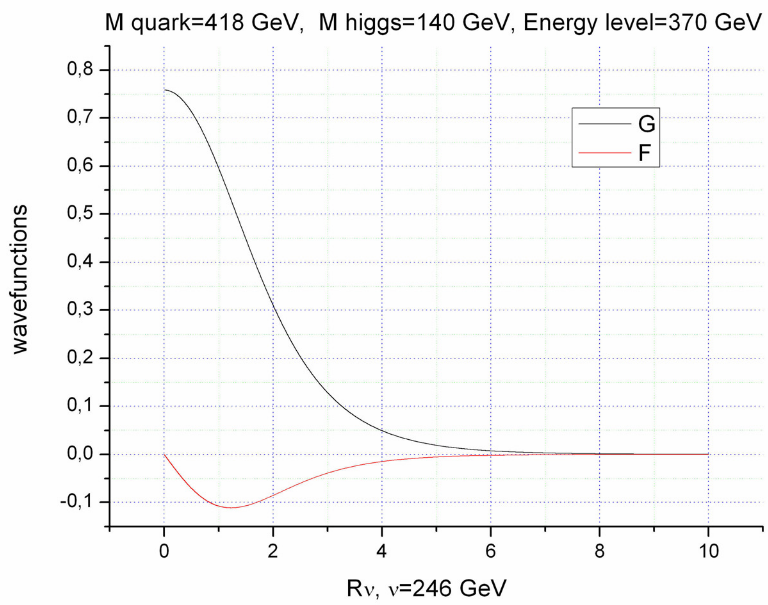
Numerical results: t´ energy in soliton “bubble”.



For large asymptotical mass of t´, the energy of the quark in the “bubble” becomes relatively smaller. Formation of the “bubble” becomes more and more favorable.

Numerical results: profiles of fields





Typical radius of the "bubble" is about 2 / VEV = 1 / M(W). It is a very essential for EW stability.

Conclusions:

Possibility of the generation of the non-topological "bubble"-like soliton in t´-Higgs system was discussed .

Critical value of t´ mass for t´-ball generation was founded.

Physical properties of such states was studied.

New experimental dates about TeV-physics are expected from LHC!