Nonlocal quark model for modelling a composite Higgs particle

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Objectives

1. To prove that in nonlocal generalizations of chiral quark models of the Nambu–Jona-Lasinio (NJL) type a composite scalar meson can be a true bound state with a mass well below the sum of masses of its constituents.
2. To apply such models to a description of the Higgs boson as a composite scalar meson, bound state of top-antitop quarks that receive their mass from dynamical chiral symmetry breaking.

Introduction

- The Higgs boson particle is an important component of the Standard Model. In 2013, a new particle with mass **125, 09** GeV, matching the requirements of the Higgs boson, was discovered at CERN.
- However, a few problems with the Higgs boson, which has spin 0, persist: the naturalness problem, the problem of triviality and the hierarchy problem.
- One possible solution to these problems is to consider the Higgs boson as a composite particle. The first attempt to represent the Higgs boson as a composite particle, consisting of top – anti-top quarks, was undertaken by Bardeen, Hill and Lindner [1]. By considering renormalization group theory within a local quark model, they obtained a result that the mass of the composite particle can be lower than sum of mass its constituents. However, within Bardeen theory, we see that the running coupling does not give us a sufficiently smaller masses.
- An alternative approach would be to consider a composite particle within a model where effective vertex interactions are delocalised [2].

Nonlocal Nambu Quark Model for Scalar Bound State

- By idea of nonlocal effective theory we consider theory with current-current interaction in vertex, but with delocalized particles. Particles in such models, which interact with each other, have different coordinates in the space. The effective action for nonlocal Nambu model has the form like action for the local case

$$S = \int d^4x \left(\bar{q}(x)(-i\partial\!\!\!/ + m)q(x) - \frac{G}{2} J(x)J(x) \right). \quad (1)$$

The general difference between local and nonlocal models is in the current $J(x)$, for nonlocal version the current has the form [3]

$$J(x) = \int d^4z g(z) \bar{q}(x + \frac{z}{2}) q(x - \frac{z}{2}), \quad (2)$$

where $g(z)$ is a form factor which responsible for the space separation of interacting particles. We can chose this form factor of Gaussian or Lorentzian type in momentum space as follow

$$g_G(k) = \exp\left(-\frac{k}{\Lambda_G}\right)^2 \quad \text{and} \quad g_L(k) = \left(1 + \left(\frac{k}{\Lambda_L}\right)^{2\alpha}\right)^{-1}, \quad (3)$$

where α and Λ are the regularization parameters.
- The Bethe-Salpeter equation and gap equations within these theories have the form

$$m(k) = 2GN_f N_c \int \frac{d^3k}{(2\pi)^3} g(k) \frac{m(k)}{E(k)}, \quad (4)$$

where N_f is the number of flavours, N_c is the number of colors, $g(k)$ is the form factor, which depends on a regularization method, and $E(k)$ is the dispersion relation

$$M^2 = 4m^2(0) + \frac{4m_0}{v} \langle\langle g^{-1}(p)(E^2(p) - \frac{M^2}{4}) \rangle\rangle - 4\langle\langle m^2(0) - m^2(p) \rangle\rangle, \quad (5)$$

where $\langle\langle A \rangle\rangle$ must be understood as

$$\langle\langle A \rangle\rangle = \left(\int dpp^2 \frac{g^2(p)}{E(p)} \frac{A}{E^2(p) - M^2/4} \right) \times \left(\int dpp^2 \frac{g^2(p)}{E(p)} \frac{1}{E^2(p) - M^2/4} \right)^{-1}. \quad (6)$$

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Results: Table

	$\alpha = 1,01$	$\alpha = 2$	Gaussian
$G\Lambda^2$	$3,35$	$7,643$	$6,01$
$G \cdot 10^{-5}$ [GeV^{-2}]	188	$415,6$	$178,9$
Λ [GeV]	$42,21$	$42,85$	$58,1$

Table 1: Coupling constants G and cut-off parameters Λ for different form factors $g(x)$

Results: Figure

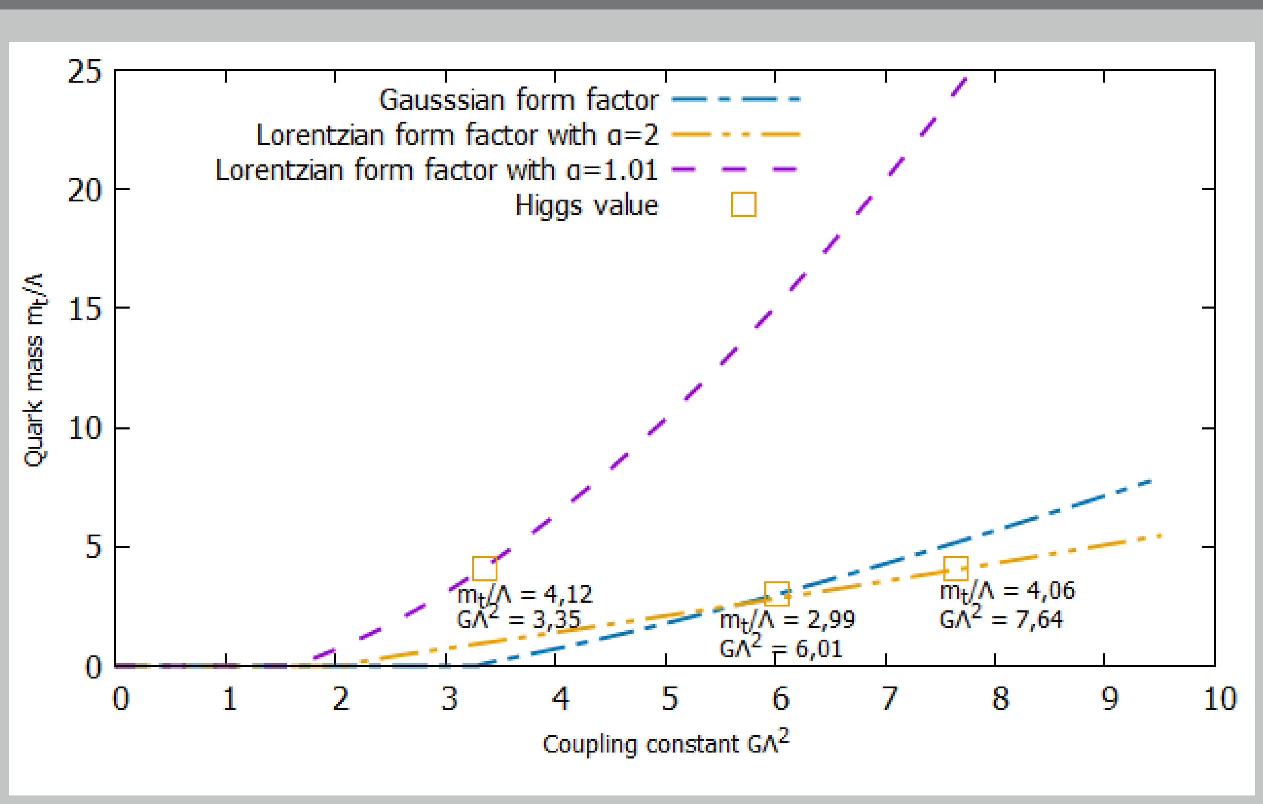

Figure 1: Mass of quark, dependence on $G\Lambda^2$

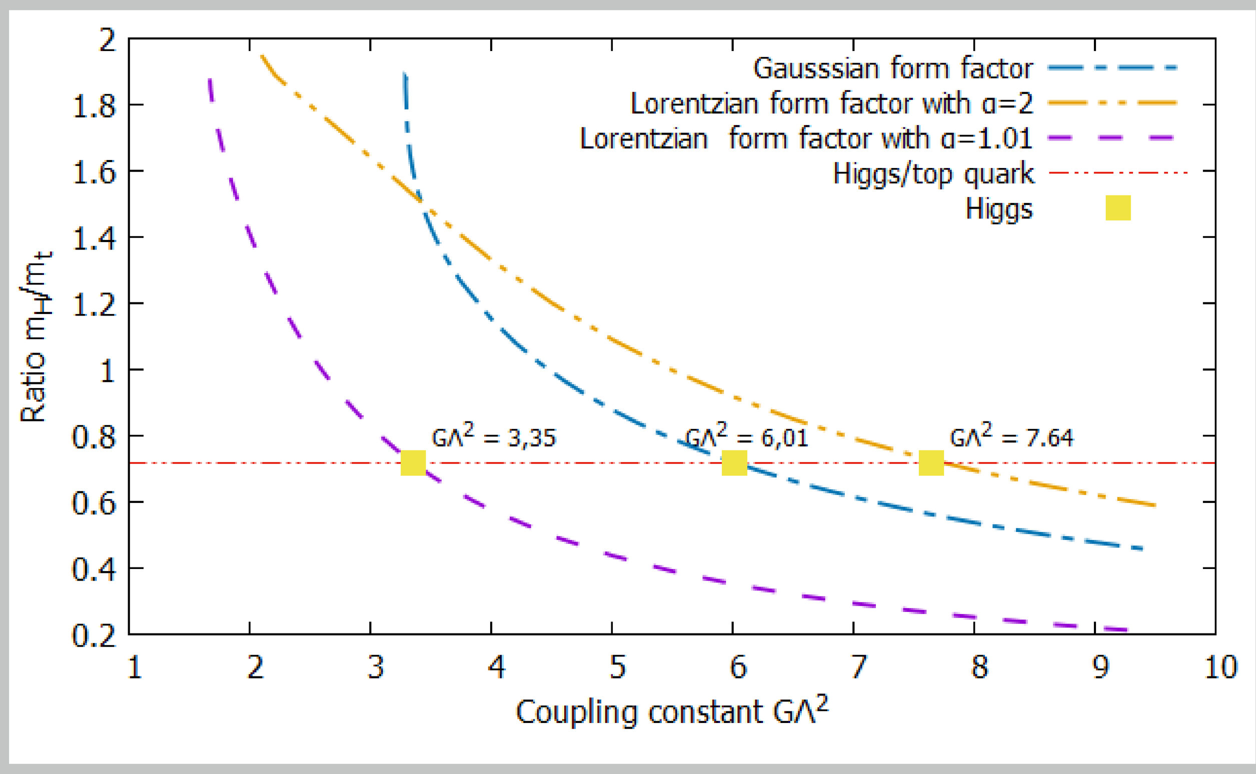

Figure 2: Dimensionless masses ratio of the Higgs boson and top quark

Conclusion

- We demonstrated for 3 examples of nonlocality formfactors the possibility to explain the Higgs boson as a composite scalar meson bound state of top-antitop quarks which get their mass from dynamical chiral symmetry breaking
- The effective range Lambda is of the order of the electroweak gauge boson mass while the coupling strength G of the model is two orders larger than the Fermi coupling G_F.
- The two free parameters form a dimensionless number $G\Lambda^2$ which for our examples lies in the range **3.35 . . . 7.64** suggesting a possibility to unify the heavy with the light quark sector where $G\Lambda^2 \sim$ **5.6** is found in these models.
- The model can be extended to consider fermion doublets, the pseudoscalar sector and Higgs mechanism, the inclusion of light quark sectors and low-energy QCD phenomenology.

References

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[2] S. M. Schmidt, D. Blaschke and Y. L. Kalinovsky, Phys. Rev. C **50** (1994) 435.

[3] D. Gomez Dumm, A. G. Grunfeld and N. N. Scoccola, Phys. Rev. D **74** (2006) 054026 [hep-ph/0607023].

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