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A Boost for a Whole Life*

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Abstract. In this paper the author would like to give a tribute to the wise guidance of his teacher during more than 30 years of common research.

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1 The Beginning

In 1977, as a four-year student at the Moscow State University, I joined Kadyshevsky's group after successful examination on Quantum Field Theory (QFT). Then for a first time I met the Bulgarian physicist Matey Dragomirov Mateev, who was one of the members of the examination group. My supervisor Professor Kadyshevsky has been the leader of the group, which was engaged with the ambitious aim of constructing QFT with the fundamental length. I was very proud of this, because the theme of the project has opened a very wide spectrum of different approaches, models and tools of the modern physics.

Shortly after my supervisor left for Fermilab and suggested his best friend Matey Mateev as a co-supervisor. Since then our fruitful collaboration began and continued until the last days of Mateev's life. Working at the JINR Laboratory of Theoretical Physics in Dubna, Russia, we met every day discussing my homework and Kadyshevsky's letters from Fermilab. These were unforgettable times!

My first scientific publication [1] was just in collaboration with my supervisors V.G. Kadyshevsky and M.D. Mateev. On the way to prepare the publication I have studied the seminal works on the dynamical symmetry breaking of the prominent scientists as W. Heisenberg, J. Schwinger, N.N. Bogolyubov, J. Fröhlich, W. Thirring, Y. Nambu, G. Jona-Lasinio, V.G. Vaks, A.I. Larkin, B.A. Arbuzov, A.N. Tavkhelidze, R.N. Faustov, D.A. Kirzhnits, D.J. Gross, A. Neveu and many others. We have exploited Heisenberg's idea about the four-fermion universal interaction. Developing further these ideas we have prepared

*Dedicated to the memory of my teacher Professor Mateev a new paper in collaboration with M.D. Mateev, however, he withdrew his name thus giving me a possibility to start my independent scientific carrier. My second paper discussed anomalous expectation values of multicomponent fields [2] and defined the main part of my scientific interests for many years.

The key point in the paper was the consideration of new excitations in $\Psi\,\Psi$ and $\overline{\Psi}\,\overline{\Psi}$ channels in QFT *à la* Bogolyubov's quasiparticles in the nonrelativistic dynamics [3]. For the first time all channels in Hartree–Fock–Bogolyubov approximation have been investigated and new Fierz identities have been derived. At present it is very popular to discuss diquark excitations, color superconductivity and so on, which have been drawn about 30 years ago.

However, at that time my interests have been completely attracted by the construction of QFT models with dynamical symmetry breaking mechanism. So, a toy model has been considered for Bogolubov's spontaneous symmetry-breaking mechanism and the Higgs phenomenon [4]. In such type of models the gauge coupling and the self-coupling of the Higgs field occur to be related as in the supersymmetry [5].

A more realistic grand unified model, based on exceptional E_6 group, has been proposed in Ref. [6]. Moreover, it has been shown that E_6 is the *minimal group* in the E-chain of the Dynkin diagrams which allows the construction of a unified model of elementary particles in the framework of the *Bogolubov method* for dynamical symmetry breaking. Nowadays when we know that the anomaly free superstring theories contain E_6 as a subgroup, this result seems natural. In 1982, however, working on exceptional groups, it was considered quite unusual. Proceeding in the same way the explicit form of an effective Higgs potential with E_6 symmetry has been also obtained [7].

Some confirmation of the developed methods has been provided considering exactly solvable models [8]. These methods for construction of dynamical composite elementary particle models could be considered as a physical basis for the mathematical methods of singular solutions of renormalization group equations [9] and the reduction schemes introduced later on by W. Zimmermann [10]. These models are defined by only one coupling constant and, therefore, possess a significant prediction power.

2 Continuation in Sofia

Although Matey Dragomirovich[1] Mateev left for Bulgaria in 1980, we continued our fruitful collaboration and friendly relations. They became closer after my moving to Bulgaria in 1990. There – on a new place – I decided to start again with our old topic on the dynamical symmetry breaking and to reconsider some issues after a period around ten years.

[1] I was calling him in this way (in Russian manner) all the time.

Using one-flavor Nambu–Jona-Lasinio (NJL) model [11] I have tried to investigate properties of all possible excitations in various channels. My attention was attracted by the tensor channel with new chiral-invariant tensor-tensor interactions, which have been missed from one-flavor NJL model. Later I have found even a statement [12] that it is impossible to introduce such type of interactions due to the identity

$$\overline{\Psi}\sigma^{\alpha\beta}(1-\gamma^5)\Psi \cdot \overline{\Psi}\sigma_{\alpha\beta}(1+\gamma^5)\Psi \equiv 0. \tag{1}$$

Nevertheless, the effective chiral-invariant interaction of this type could be obtained in a unique way in the form

$$\mathcal{L}_T = -\frac{G_T}{2}\overline{\Psi}\sigma^{\alpha\lambda}(1-\gamma^5)\Psi\,\frac{q_\alpha q^\beta}{q^2}\,\overline{\Psi}\sigma_{\beta\lambda}(1+\gamma^5)\Psi, \tag{2}$$

which depends on the transfer momentum, q, between the tensor currents.

So, in addition to the known (pseudo)scalar and (axial)vector excitations with the quantum numbers $(0^{-+})\,0^{++}$ and $(1^{++})1^{--}$, correspondingly, new (axial)vector excitations with the quantum numbers $(1^{+-})1^{--}$, have been introduced [13]. The introduction of the excited states with the new quantum numbers 1^{+-} had crucial consequences for collider physics later on.

For the hadron physics there are direct consequences already, which have been tested experimentally. So, there exist two different particles with the same quantum numbers, 1^{--}, and the physical states, ρ and ρ' vector mesons, are a mixture of them. The data prefer the maximal mixing and these mesons posses big anomalous couplings with the quark tensor current.

The axial-vector particles, b_1, with quantum numbers, 1^{+-}, have only anomalous interactions with the fermion matter. Up to now only the minimal gauge interactions for spin-1 particles have been considered, while the anomalous interactions have been treated as quantum corrections. Therefore, the consideration of the new excitations introduces a new type of particles, which have not been investigated before.

Besides the dynamical characteristics, the NJL model allows to obtain new mass relations [14], which are satisfied experimentally. They do not follow from the unitary symmetries but are based on the low-energy chiral quark dynamics and mixed mesons even with different parities like the well-known Weinberg relation [15].

The next step in the development of these ideas is hinted by history. Many years ago vector ρ and axial-vector a_1 resonances have brought Weinberg to the idea of the photon and the weak bosons. In his recollections [16] Weinberg states that "The right place to apply these ideas was not to the strong interactions, but to the weak and electromagnetic interactions." Nature, besides a_1, provides us with one more axial-vector boson b_1. Due to its quantum numbers, this boson does not mix with others and it has only anomalous interactions (it does not preserve helicities) with matter. What is its role in the high energy physics?

3 Prediction of New Resonances

An extension of the SM by the new spin-1 particles, having only anomalous interactions, has been proposed already in [17]. Since such particles do not preserve helicities, they should be introduced as electroweak doublets $(Z^* \ W^*)$ with the internal quantum numbers identical to the SM Higgs doublet. It has been observed that they possess new unique signatures at the hadron colliders [18]. Based on these properties a proposal for their search at the LHC has been written [19].

This proposal has been accepted by the ATLAS Collaboration and already two papers [20] and [21] have been published, which included the search for such resonances. A particular role for this decision played the recent publication [22], which has shown that these states are necessary in many theories solving the Hierarchy problem. Based on the 2010 data the following constraints on the resonance masses have been obtained $M_{W^*} > 1350$ GeV and $M_{Z^*} > 1152$ GeV.

4 Conclusions

A couple of months before the tragic incident Professor Mateev presented our proposal at the R-ECFA meeting in Sofia. He was proud that one of his students played the leading role in it. Once he wondered how just one paper could define the direction for a whole life.

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