

HOW IS EXOTICS PRODUCED ? WHERE TO SEARCH FOR IT ?

Ya.Azimov^{*,1}, K.Goeke[%], and I.Strakovsky[#]

^{*}Petersburg Nuclear Physics Institute, Gatchina, Russia

[%]Ruhr-Universität, Bochum, Germany

[#]George Washington University, Washington, D.C., USA

Abstract

On the basis of existing data, we suggest such a mechanism of production for exotic hadrons that can explain, at least qualitatively, why the Θ^+ -baryon is seen in some experiments and not in others. With our hypothesis, production of exotic hadrons is a new kind of hard processes. We also can propose new experiments to check (and confirm?) existence of exotics and to provide new important information about both exotic and conventional hadrons².

1 Introduction

The problem of exotic hadrons (*i.e.*, non- qqq baryons and/or non- $q\bar{q}$ mesons) stays open. Theoretical studies are uncertain and do not provide any convincing explanation, whether and why such hadrons might/should not exist. But experimental situation is also uncertain in respect to their existence [2].

There are mesons (scalar mesons and some of recently discovered ones) interpreted in the literature as tetraquark ($2q2\bar{q}$) states, but this interpretation is strongly model dependent. Their conventional $q\bar{q}$ interpretation cannot be rejected as well, while rare experimental evidences for explicitly non- $q\bar{q}$ mesons are not sufficiently reliable yet.

The situation may be different for baryons. There are experimental evidences for three explicitly exotic states: $\Theta^+(1530)$, $\Theta_c^0(3100)$, and $\Xi_{3/2}^-(1860)$ (or $\Phi^{--}(1860)$) [2]. However, each of the two latter states was seen by one group only. They have not been found in later dedicated experiments, and we will not discuss them here.

At present, more crucial looks the existence or non-existence of the Θ^+ . The corresponding information is much more copious than for any other

¹E-mail address: azimov@thd.pnpi.spb.ru

²The talk is based on the papers [1].

exotic hadron candidate. But the problem is that there are both positive and negative results, of several groups on each side.

With such data, one can take a viewpoint that all positive results might emerge as statistical fluctuations and not reveal a true physical object. It would be strange, however, to have the same fluctuation in data of more than ten independent groups studying very different processes. Moreover, in such a case we should still live with the open question of what prevents exotic hadrons from being existent and observed.

An opposite viewpoint is that the Θ^+ , as a representative of exotic hadrons, does exist and has properties corresponding to the published positive evidences: rather low mass and unexpectedly narrow width. Then the problem is whether such an unfamiliar production mechanism may exist, with which all the present positive and null data are consistent to each other.

2 Θ^+ Production Mechanism

The ZEUS Collaboration was the first experimental group to study not only existence of the Θ^+ , but also its production properties in Deep Inelastic Scattering (DIS). They compared, in the same kinematical region, characteristics of the three baryons, $\Lambda(1520)$, $\Lambda_c^+(2286)$, and $\Theta^+(1530)$, which could be kinematically similar. However, all three appeared dynamically different [3].

To understand the results, let us first recall the nature of the DIS process. The target hadron (proton at HERA) looks in this process as a set of many partons. At the hard stage of the process, one (or a few number) of the partons is knocked out by the virtual γ/Z . After that, the knocked-out parton(s) and the remnant part of the target hadronize, softly and nearly independently of each other.

The ZEUS results [3] show, that production of the $\Lambda(1520)$ is well described by hadronization of the knocked-out parton-quark, exactly as was expected. Production of the $\Lambda_c^+(2286)$ (or its antiparticle) goes in a different, but also expected way: the virtual γ/Z collides with the parton-gluon, they produce the $c\bar{c}$ -pair, which then hadronizes. Contrary to those, production properties of the $\Theta^+(1530)$ give evidence, quite unexpectedly, that it comes from hadronization of the proton remnant.

Since the remnant is, evidently, a many-parton state, we can generalize this fact as **the Hypothesis**:

- Multiquark (exotic) hadrons are mainly produced through many-parton configurations, which may emerge either as hadron remnants in hard processes or just as virtual short-term fluctuations of the initial hadron(s).

Note that in terms of Quantum Chromodynamics (QCD) any hadron may be described by a Fock column, with different components having different number of partons. In the space-time picture, the short-term fluctuations of a hadron are related with higher Fock components. Hadron picture, as seen in DIS, is also related with higher Fock components. Thus, in framework of our hypothesis, the Θ^+ -production is always due to short-term fluctuations and, at least some stage of this process, should have small characteristic time. This means that the exotics production is, intrinsically, a new kind of hard processes. Of course, it differs from DIS and many other hard processes, that have a continuous parameter to measure the hardness (the photon virtuality Q^2 for DIS). But it is similar to the heavy quark production, having the quark mass as a fixed hardness parameter. For the exotics production, hardness may be related to the fixed minimal number of additional $q\bar{q}$ pairs.

3 Checks for the Production Mechanism

Now we can suggest some immediate checks for the hypothesis.

The more is virtuality Q^2 in DIS, the higher is effective multiplicity of partons in the target. Therefore, we expect that increasing Q^2 should provide some (logarithmically increasing?) enhancement of exotics (say, the Θ^+) production in respect to conventional hadrons. Such expectation does not contradict to the preliminary ZEUS data [4], though present rather large experimental errors do not allow to make a clear conclusion. The situation reminds the case of the Bjorken scaling, which looked exact in early data, while later more exact measurements revealed its violation.

Our hypothesis suggests interesting expectations not only for DIS, but also for exotics production in “soft processes”. If it needs indeed participation of many-parton fluctuations, then the accompanying hadron multiplicity should be higher than in conventional hadron production. Because of kinematical reasons, this should generate energy spectra, which is softer for exotics production than for production of only conventional hadrons. Such expectation appears to be in good correspondence with the recent result of the SVD Collaboration [5], that in NN collisions at $E_{\text{lab}} = 70$ GeV the inclusive spectrum for $\Theta^+(1530)$ is essentially softer than for $\Lambda(1520)$.

Additional, indirect support to our hypothesis comes from calculations of the Θ^+ width [6]. They show that the extremely low experimental value $\Gamma_{\Theta^+} = (0.36 \pm 0.11)$ MeV [7] can be described if the decay $\Theta \rightarrow KN$ goes mainly to higher Fock components of the final nucleon. Our hypothesis applies similar approach to production processes as well.

Analysis of Ref. [1] shows that the hypothesis provides also qualitative

ways to reconcile current positive and null experiments (in particular, CLAS and LEPS data [8]). It allows as well to suggest new experiments (or modification of existing ones) which may confirm and investigate exotic hadrons.

Acknowledgments

The work was partly supported by the Russian Grant RSGSS-1124.2003.2, by the Russian-German Collaboration Treaty (RFBR, DFG), by the COSY-Project Jülich, by Verbundforschung “Hadronen und Kerne” of the BMBF, by Transregio/SFB Bonn, Bochum, Giessen of the DFG, by the U. S. Department of Energy Grant DE-FG02-99ER41110, by the Jefferson Laboratory, and by the Southeastern Universities Research Association under DOE Contract DE-AC05-84ER40150.

References

- [1] Ya. Azimov, K. Goeke, and I. Strakovsky, arXiv:0704.3045.
Ya. Azimov, K. Goeke, and I. Strakovsky, *Phys. Rev.* **D76**, 074013 (2007).
- [2] W.-M. Yao *et al.* [Particle Data Group], *J. Phys.* **G33**, 1 (2006).
- [3] S. Chekanov [H1 and ZEUS Collab.], in *Proc. Int. Europhys. Conf. on High-Energy Physics (July 21-27, 2005) Lisboa, Portugal*; Proc. Sci., HEP2005, 086 (2006); arXiv:hep-ex/0510057.
- [4] U. Karshon [ZEUS Collab.], in *Proc. Int. Workshop PENTAQUARK04, SPring-8, Hyogo, Japan, 2004*, p. 75; arXiv:hep-ex/0410029.
- [5] A. Kubarovsky, V. Popov, and V. Volkov [SVD Collab.], in *Proc. of the 33rd Int. Conf. on High Energy Physics (ICHEP'06), Moscow, Russia, July 26 - August 2, 2006*; arXiv:hep-ex/0610050.
- [6] D. Diakonov and V. Petrov, *Phys. Rev.* **D72**, 074009 (2005).
C. Lorce, *Phys. Rev.* **D74**, 054019 (2006).
C. Lorce, arXiv:0705.1505.
- [7] V. V. Barmin *et al.* [DIANA Collab.], *Yad. Fiz.* **70**, 39 (2007) [*Phys. At. Nucl.* **70**, 35 (2007)].
- [8] T. Nakano [LEPS Collab.], talk at this Conference, (<http://www.fz-juelich.de/ikp/menu2007/Talks/talk-Nakano.pdf>).