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# Resonances in the Constituent-Quark Model*

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**Abstract.** We give a short account of the present description of baryon resonances within the relativistic constituent-quark model, where resonances are usually treated as excited bound states, and point to ways for a more realistic theory producing the resonances as complex poles in the momentum/energy planes, i.e. with real mass values and finite widths.

Nowadays the relativistic constituent-quark model, especially the one relying on a dynamics of linear confinement and a hyperfine interaction of Goldstone-boson exchange [1, 2], can provide a reasonable description of the baryon spectra (see, e.g., the recent review in ref. [3]. It is even possible to reproduce - with only a few exceptions - the real mass values of all known baryon ground and resonant states with flavors u, d, s, c, and b in a universal framework in close agreement with phenomenology or data from lattice chromodynamics (QCD) [4–7]. Herein baryons are considered as relativistic bound states of three confined constituent quarks Q interacting mutually. The Q's are supposed to be quasi-particles with dynamical masses generated by the spontaneous breaking of chiral symmetry (SB$\chi$S) of low-energy QCD [8, 9]. The most important ingredients in the three-Q invariant mass operator turn out to be SB$\chi$S and relativistic invariance [10].

Solving the three-Q mass-operator eigenvalue problem provides also access to the baryon eigenfunctions (see, e.g., their rest-frame spatial representations in ref. [12]). They can be subject to tests in various baryon reactions. While their structures appear to be quite reasonable for the baryon ground states, the resonance wave functions are obviously affected by shortcomings.

In particular, the electromagnetic form factors of the nucleons as well as their electric radii and magnetic moments are reproduced in good agreement with phenomenology [13], even with regard to their flavor contents [14]. Similarly, the electromagnetic form factors, electric radii, and magnetic moments of the $\Delta$ and hyperon ground states are found well compatible with available data from experiment and lattice QCD [15, 16]. The same is true with regard to the axial form factors and axial charges [16–18]. Likewise, the gravitational form factor $A(Q^2)$ of the nucleons is reasonably reproduced [3]. In addition, for the strong form factors of the $\pi$NN and $\pi$N$\Delta$ a microscopic explanation is provided that conforms with the ones usually adopted in $\pi$N and $\pi\Delta$ dynamical models [19].

* Talk delivered by by W. Plessas

Disturbing shortcomings of the three-Q constituent-quark model appear with regard to direct predictions for hadronic decays of the $\pi$, $\eta$, and K meson modes. First fully relativistic results in general show an undershooting of the experimental decay widths [12, 20–22]. This hints to missing ingredients in the adopted approach. The problems may either be connected with an improper treatment of the meson-decay vertex or missing degrees of freedom from the decay channels.

In order to remedy the situation we have recently adhered to a coupled-channels formalism, taking into account mesonic decays channels explicitly. First attempts along a toy model for mesons yielded promising results [23]. At least it could be shown, how finite resonance widths well develop in such an approach.

Further studies concerned explicit pionic effects both on the ground state and resonance masses (including the resonance widths), exemplified for the nucleon and the $\Delta$. Details of the formalism and first results were presented at previous Bled Workshops [24–26]. While the pionic effects on the nucleon mass appear reasonable, the analogous treatment of the $\Delta$ does not yet enhance especially its $\pi$-decay width enough in order to make it compatible with the relatively large phenomenological value [26]. Further ingredients appear to be necessary. We are presently in the course of extending the coupled-channels theory accordingly.

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## References

1. L. Y. Glozman, W. Plessas, K. Varga and R. F. Wagenbrunn, Phys. Rev. D **58**, 094030 (1998)
2. L. Y. Glozman, Z. Papp, W. Plessas, K. Varga and R. F. Wagenbrunn, Phys. Rev. C **57**, 3406 (1998)
3. W. Plessas, Int. J. Mod. Phys. A **30**, no. 02, 1530013 (2015)
4. J. P. Day, W. Plessas, and K. S. Choi, arXiv:1205.6918 [hep-ph]
5. J. P. Day, K. S. Choi, and W. Plessas, Few-Body Syst. **54**, 329 (2013)
6. J. P. Day, W. Plessas, and K. S. Choi, in: *Looking into Hadrons* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2013), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2013); p. 6
7. J. P. Day, PhD Thesis, University of Graz (2013)
8. W. Plessas, in: *Quark Masses and Hadron Spectra* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2014), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2014); p. 34

9. M. Rosina, in: *Quark Masses and Hadron Spectra* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2014), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2014); p. 50
10. W. Plessas, Mod. Phys. Lett. A **28**, no. 26, 1360022 (2013)
11. W. Plessas, PoS LC **2010**, 017 (2010); arXiv:1011.0156 [hep-ph]
12. T. Melde, W. Plessas and B. Sengl, Phys. Rev. D **77**, 114002 (2008)
13. R. F. Wagenbrunn, S. Boffi, W. Klink, W. Plessas, and M. Radici, Phys. Lett. B **511**, 33 (2001)
14. M. Rohrmoser, K. S. Choi, and W. Plessas, Acta Phys. Polon. Supp. **6**, 371 (2013)
15. K. Berger, R. F. Wagenbrunn, and W. Plessas, Phys. Rev. D **70**, 094027 (2004)
16. K. S. Choi and W. Plessas, Few-Body Syst. **54**, 1055 (2013)
17. L. Y. Glozman, M. Radici, R. F. Wagenbrunn, S. Boffi, W. Klink, and W. Plessas, Phys. Lett. B **516**, 183 (2001)
18. S. Boffi, L. Y. Glozman, W. Klink, W. Plessas, M. Radici, and R. F. Wagenbrunn, Eur. Phys. J. A **14**, 17 (2002)
19. T. Melde, L. Canton, and W. Plessas, Phys. Rev. Lett. **102**, 132002 (2009)
20. T. Melde, W. Plessas, and R. F. Wagenbrunn, Phys. Rev. C **72**, 015207 (2005); ibid. C **74**, 069901 (2006)
21. B. Sengl, T. Melde, and W. Plessas, Phys. Rev. D **76**, 054008 (2007)
22. T. Melde, W. Plessas, and B. Sengl, Phys. Rev. C **76**, 025204 (2007)
23. R. Kleinhappel, W. Plessas, and W. Schweiger, Few-Body Syst. **54**, 339 (2013)
24. R. Kleinhappel, W. Plessas, and W. Schweiger, in: *Understanding Hadron Spectra* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2011), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2011); p. 36
25. R. Kleinhappel, W. Plessas, and W. Schweiger, in: *Hadronic Resonances* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2012), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2012); p. 20
26. R. Kleinhappel, L. Canton, W. Plessas, and W. Schweiger, in: *Quark Masses and Hadron Spectra* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2014), ed. by B. Golli, M. Rosina, and S. Sirca. DMFA, Ljubljana (2014); p. 22

## Analitična zgradba neperturbativnih kvarkovih propagatorjev in mezonskih procesov

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Raziskujemo analitično zgradbo nekaterih nastavkov za kvarkove propagatorje v neperturbativnem področju kromodinamike. Če izberemo fizikalno motivirano parametrizacijo masne funkcije $M(p^2)$ oblečenih kvarkov, odvisne od gibalne količine in z določeno analitično zgradbo, je skrajno težavno napovedati in obvladati analitično zgradbo ustreznega neperturbativnega kvarkovega propagatorja. Tudi problem Wickove rotacije, ki povezuje izražavo v prostoru Minkowskega in Evklida, je skrajno težaven v neperturbativnem območju. Izpeljemo obliko propagatorja, ki omogoča Wickovo rotacijo in dopušča enakovredne račune v prostoru Minkowskega in Evklida. Kljub preprostosti nudi ta model dober kvalitativen in semikvantitativen opis nekaterih procesov z psevdoskalarnimi mezoni.

## Primerjava med mezoni in resonancami $W_L W_L$ pri energijah več TeV

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Mikavni signali z Velikega hadronskega trkalnika (LHC) namigujejo, da morda obstajajo v področju zloma elektro-šibke simetrije resonance v območju več TeV. Spomnimo na nekaj ključnih resonanc mezon-mezon v območju GeV, ki bi utegnile imeti analogne resonance pri visokih energijah in nam služijo za primerjavo, hkrati z odgovarjujočo unitarizirano efektivno teorijo. Čeprav je podrobna dinamika lahko različna, pa zahteve po unitarnosti, kavzalnosti in globalnem zlomu simetrije (z uporabo metode inverzne amplitude) dovoljujejo prenos intuicije v večinoma neizmerjeno območje visokih energij. Če bo povečano število dogodkov na ATLASU okrog 2 TeV podprlo tako novo resonanco, to lahko pomeni anomalno sklopitev $q\bar{q}W$.

## Resonance v konstituentnem kvarkovem modelu.

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Na kratko poročamo o današnjem opisu barionskih resonanc v realističnem modelu s konstituentnimi kvarki, v katerem običajno obravnavamo resonance kot

vzbujena vezana stanja, in pokažemo pot do bolj realistične teorije, v kateri nastopijo resonance kot kompleksni poli v ravnini gibalna količina/energija, torej z realno maso in končno širino.

## Račun vzbujenih resonanc mezona ρ in faznih premikov ππ v P-valu z razširjenim kvarkovim modelom

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Raziskujemo vektorsko resonanco $\rho(770)$, njene radialne ponovitve ter ustrezne fazne premike ππ v P-valu z razširjenim kvarkovim modelom, ki vsebuje tudi pare mezonov in pare $q\bar{q}$. Pri tem upoštevamo vse važne razpadne kanale: psevdoskalar-psevdoskalar, vektor- psevdoskalar, vektor-vektor, vektor-skalar, aksialni vektor-psevdoskalar in aksialni vektor-vektor, skupaj 26 kanalov. Dva modelska parametra sta določena s prejšnjimi vrednostmi, trije pa iz resonance ρ in nizkoenergijskih faznih premikov ππ v P-valu. Začasni rezultati že nakazujejo sposobnost modela, da reproducira te fazne premike ter maso in širino mezona ρ. Vendar rastejo fazni premiki pri višjih energijah prestrmo. Možno zdravilo je vključitev resonanc v končnih stanjih v večini kanalov. Raziskava se nadaljuje.

## Prispevek pionskega oblaka k elektromagnetni strukturi nukleona

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V tem prispevku nadaljujemo in razširimo prejšnje račune elektro-šibkih oblikovnih faktorjev hadronov z uporabo točkovne oblike relativistične kvantne mehanike. Posebej se zanimamo za pionske učinke na elektromagnetno zgradbo nukleona. V ta namen uporabimo hibridni model s konstituentnimi kvarki, ki vsebuje poleg trojice valenčnih kvarkov še komponento $3q+\pi$. S preprosto valovno funkcijo za konfiguracijo 3q dobimo smiselne rezultate za oblikovne faktorje nukleona. V skladu z drugimim avtorji ugotovimo, da je učinek pionov znaten le pod $Q^2 \leq 0.5\ \mathrm{GeV}^2$.