BLED WORKSHOPS
IN PHYSICS
VOL. 15, NO. 1
p. 22

Proceedings of the Mini-Workshop
Quark Masses and Hadron Spectra
Bled, Slovenia, July 6 - 13, 2014

Mesonic Effects in Baryon Ground and Resonant States*

R. Kleinhappel[a], L. Canton[b], W. Plessas[a], and W. Schweiger[a]

[a] Theoretical Physics, Institute of Physics, University of Graz, Universitätsplatz 5, A-8010 Graz, Austria
[b] Istituto Nazionale di Fisica Nucleare, Via F. Marzolo 8, I-35131 Padova, Italy

Abstract. We investigate mesonic effects in baryon ground and resonant states by including meson loops in a relativistic coupled-channels approach. From calculations, so far done on the hadronic level, we obtain results for the dressed mass of the nucleon ground state and for dressed masses and decay widths of resonances, notably of the Δ, due to coupling to the pion channel. At this stage an improvement is found over the single-channel theory, the experimental data for decay widths, however, are still underestimated.

A proper description of hadron resonances still represents a big challenge in quantum chromodynamics (QCD), irrespective of the approach followed. Particularly in the framework of constituent-quark models, hadronic resonances are usually treated as excited bound states rather than as resonant states with finite widths. Calculations of strong decays have thus shown short-comings generally producing too small decay widths [1–4]. To remedy this situation we are investigating a coupled-channels (CC) approach taking into account explicit meson, especially pionic, degrees of freedom.

The CC approach has been tested before within a simple scalar toy model, leaving out all spin and flavor dependences. It turned out that the coupling to a mesonic channel shifts the ground-state mass down and generates the resonant state with a finite width, whose magnitude is dependent essentially on the coupling strength to the meson channel [5, 6]. Recently we have obtained results for the πNN and the $\pi N\Delta$ systems, including all spin and flavor degrees of freedom.

Our theory relies on a relativistically invariant mass operator written in matrix form. It contains a bare baryon state i, here the N or Δ, coupled to the πNN and the $\pi N\Delta$ channels $i+1$, respectively. After eliminating the latter by the Feshbach method one ends up with the following eigenvalue problem for the dressed baryon ground or resonant state $|\psi_i>$:

$$\left[M_i - K\left(m - M_{i+1} + i0\right)^{-1} K^{\dagger}\right] |\psi_i> = m|\psi_i> \ . \qquad (1)$$

Evidently, it contains an optical potential, which becomes complex above the πN threshold. Herein, M_i and M_{i+1} are the invariant mass operators of the i-th and

* Talk presented by R. Kleinhappel

(i+1)-st channels and K describes the transition dynamics. It should be noted that the mass eigenvalue m appears also in the optical-potential term. Beyond the resonance threshold it acquires an imaginary part leading to a finite decay widths.

The transition dynamics contained in K is deduced from the following Lagrangian densities

$$\mathcal{L}_{NN\pi} = -\frac{f_{NN\pi}}{m_\pi}\bar{\Psi}\gamma_5\gamma^\mu\Psi\partial_\mu\Phi\,, \tag{2}$$

$$\mathcal{L}_{\Delta N\pi} = -\frac{f_{\Delta N\pi}}{m_\pi}\bar{\Psi}\Psi^\mu\partial_\mu\Phi + \text{h.c.}\,. \tag{3}$$

where Ψ and Ψ^μ represent the N and Δ fields, which are coupled in pseudovector form by the π field Φ with strengths $f_{NN\pi}$ and $f_{\Delta N\pi}$, respectively. This leads to transition matrix elements from the bare $\tilde{N}$ and $\tilde{\Delta}$ states to the channels including the explicit pions (with mass m_π) for the cases of πNN

$$< \tilde{N}|\mathcal{L}_{\pi\tilde{N}\tilde{N}}(0)|\tilde{N},\pi;\mathbf{k}''_\pi >= \sum \frac{i\,f_{\pi\tilde{N}\tilde{N}}}{m_\pi}\bar{u}(k_{\tilde{N}},\Sigma_{\tilde{N}})\gamma^\mu\gamma_5 u(k''_{\tilde{N}},\Sigma''_{\tilde{N}})(k''_\pi)_\mu \tag{4}$$

and $\pi N\Delta$

$$< \tilde{\Delta}|\mathcal{L}_{\pi\tilde{N}\tilde{\Delta}}(0)|\tilde{N},\pi;\mathbf{k}''_\pi >= \sum \frac{i\,f_{\pi\tilde{N}\tilde{\Delta}}}{m_\pi}\bar{u}^\mu(k_{\tilde{\Delta}},\Sigma_{\tilde{\Delta}})u(k''_{\tilde{N}},\Sigma_{\tilde{N}})(k''_\pi)_\mu\,. \tag{5}$$

Here $u\,(k_N,\Sigma_N)$ are the spin-$\frac{1}{2}$ Dirac spinors of the N and $u^\mu\;(k_\Delta,\Sigma_\Delta)$ the spin-$\frac{3}{2}$ Rarita-Schwinger spinors of the Δ. In the rest frame of the baryon B the eigenvalue equation (1) finally turns into the following explicit form

$$\begin{aligned}\Bigg(m_{\tilde{B}} + \int \frac{d^3k''_\pi}{(2\pi)^3}\frac{1}{2\omega''_\pi 2\omega''_{\tilde{N}}2m_{\tilde{B}}}\mathcal{F}_{\pi\tilde{N}\tilde{B}}(\mathbf{k}''_\pi) < \tilde{B}|\mathcal{L}_{\pi\tilde{N}\tilde{B}}(0)|\tilde{N},\pi;\mathbf{k}''_\pi > \\ \times\left(m - \sqrt{m^2_{\tilde{N}} + \mathbf{k}''^2_\pi} - \sqrt{m^2_\pi + \mathbf{k}''^2_\pi} + i0\right)^{-1} \mathcal{F}^*_{\pi\tilde{N}\tilde{B}}(\mathbf{k}''_\pi) \\ \times < \tilde{N},\pi;\mathbf{k}''_\pi|\mathcal{L}^\dagger_{\pi\tilde{N}\tilde{N}}(0)|\tilde{B} >\Bigg) < \tilde{B}|\psi_B >= m < \tilde{B}|\psi_B >\end{aligned} \tag{6}$$

with B standing for N or Δ and all quantities with a tilde referring to bare particles. The wave functions of the baryon states $< \tilde{B}|\psi_B >$ are represented by free momentum eigenstates denoted by $< \tilde{B}|$ or equivalently by free velocity states $< \tilde{B};\mathbf{v} = 0|$ (for pertinent details see Ref. [5]). The processes corresponding to the optical potential in Eq. (6) are depicted in Fig. 1.

Fig. 1. Pion-loop diagrams for the πNN and $\pi N\Delta$ systems according to Eq. (6).

In Eq. (6) we have inserted form factors $\mathcal{F}_{\pi\tilde{N}\tilde{B}}$ for the extended meson-baryon vertices. They are taken from three different models, namely, a relativistic constituent-quark model (RCQM) [7,8] as well as two phenomenological meson-nucleon models, namely, the one by Sato and Lee (SL) [9] and the one by Polinder and Rijken (PR) [10]. The corresponding parametrizations are all given in Ref. [11] according to the form

$$F\left(\mathbf{q}^2\right) = \frac{1}{1 + \left(\frac{q}{\Lambda_1}\right)^2 + \left(\frac{q}{\Lambda_2}\right)^4} . \tag{7}$$

The cut-off parameters occurring in Eq. (7) and the values of the coupling constants are summarized in Tab. 1. The functional dependences of the various vertex form factors are shown in Figs. 2 and 3.

		RCQM	SL	PR
N	$\frac{f_N^2}{4\pi}$	0.0691	0.08	0.013
	Λ_1	0.451	0.453	0.940
	Λ_2	0.931	0.641	1.102
Δ	$\frac{f_\Delta^2}{4\pi}$	0.188	0.334	0.167
	Λ_1	0.594	0.458	0.853
	Λ_2	0.998	0.648	1.014

Table 1. πNN and $\pi N\Delta$ coupling constants as well as cut-off parameters entering into Eq. (7) for the three different form-factor models used in the present work (cf. Ref. [11]).

By solving the eigenvalue equation (6) with the physical nucleon mass $m_N = 939$ MeV as input for m we find the bare nucleon mass $m_{\tilde{N}}$ and thus the influence of the pion loop. Tab. 2 contains the results for the pion dressing of the nucleon ground state. It is seen that all three different form-factor models lead to very similar magnitudes for the mass differences $m_N - m_{\tilde{N}}$ of about 100 MeV.

	RCQM	SL	PR
$m_{\tilde{N}}$	1.067	1.031	1.051
$m_N - m_{\tilde{N}}$	-0.128	-0.092	-0.112

Table 2. Mesonic effects on the nucleon mass m_N from coupling to the πNN channel.

In the case of the Δ resonance we are interested in the mesonic effects on both the mass as well as the decay width. In the first instance, we employ a bare intermediate nucleon $\tilde{N}$ as is shown in the graph on the r.h.s. of Fig. 1. The corresponding results are given in Tab. 3. Again the pionic effects on the masses are quite similar for the three different form-factor models. The π-decay widths,

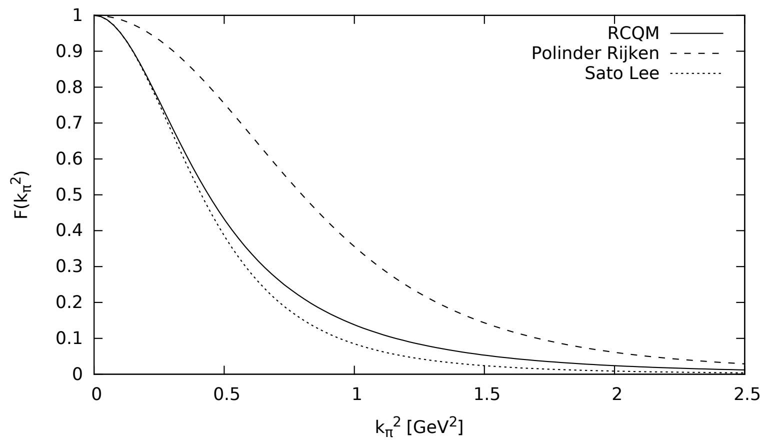

Fig. 2. Momentum dependences of the three different form-factor models in case of the πNN system.

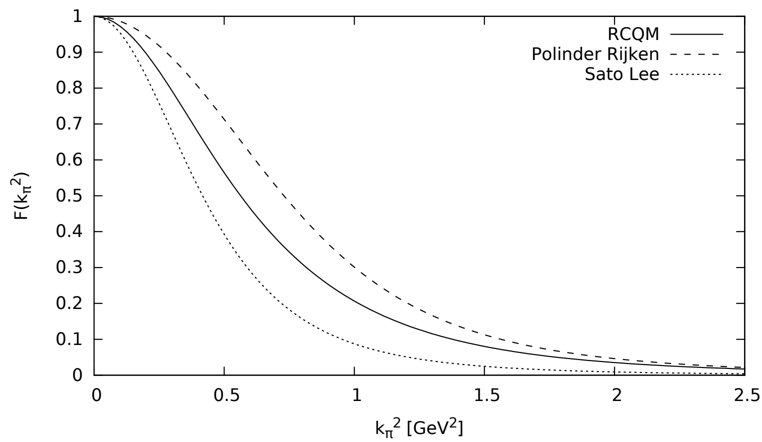

Fig. 3. Momentum dependences of the three different form-factor models in case of the $\pi N\Delta$ system.

however, show bigger variations. Still, they are all too small as compared to the phenomenological value.

A more realistic description of the $\Delta \to N\pi$ decay width is obtained by replacing the bare $\tilde{N}$ with mass $m_{\tilde{N}}$ in the intermediate state by the physical nucleon N with mass $m_N = 939$ MeV, as depicted in Fig. 4.

The corresponding results are given in Tab. 4. It is immediately seen that the decay widths get much enhanced, while the effects on the masses are only slightly changed. We expect the larger phase space for the pionic decay to be responsible for the enhancement of the decay widths.

At this stage an open problem is left with regard to dressing the vertex form factors and the coupling strengths in our work. Corresponding studies have ear-

	RCQM	SL	PR
$m_{\tilde{N}}$	1.067	1.031	1.051
$m_{\tilde{\Delta}}$	1.300	1.295	1.336
$\mathrm{Re}\,(m_\Delta) - m_{\tilde{\Delta}}$	-0.068	-0.062	-0.104
$\Gamma = 2\,\mathrm{Im}\,(m_\Delta)$	0.0026	0.017	0.0048

Table 3. Mesonic effects on the Δ mass $\mathrm{Re}\,(m_\Delta)$ and π-decay width Γ from coupling to the $\pi N\Delta$ channel, according to the loop diagram on the r.h.s. of Fig. 1. The bare nucleon masses $m_{\tilde{N}}$ are the same as in Tab. 2.

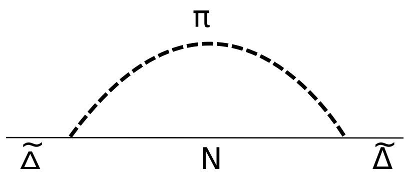

Fig. 4. Pion-loop diagram for the $\pi N\Delta$ system with an intermediate physical nucleon with mass $m_N = 939$ MeV.

	RCQM	SL	PR
m_N	0.939	0.939	0.939
$m_{\tilde{\Delta}}$	1.318	1.306	1.358
$\mathrm{Re}\,(m_\Delta) - m_{\tilde{\Delta}}$	-0.086	-0.073	-0.125
$\Gamma = 2\,\mathrm{Im}\,(m_\Delta)$	0.042	0.069	0.039

Table 4. Mesonic effects on the Δ mass $\mathrm{Re}\,(m_\Delta)$ and π-decay width Γ from coupling to the $\pi N\Delta$ channel, according to the loop diagram in Fig. 4.

lier been undertaken, e.g., by both Sato and Lee [9] as well as Polinder and Rijken [10]. We may expect a further improvement of our results by following a similar way, but it constitutes a difficult task to realize such a framework consistently in our approach.

In summary we are encouraged by the results obtained so far. We have identified the magnitudes of the pionic effects on the N ground state as well as the Δ resonance. In addition, we could demonstrate, how the pionic Δ decay width comes about by explicitly including the π-decay channel. Analogous investigations are presently under way for the N^* resonances.

Acknowledgment

This work was supported by the Austrian Science Fund, FWF, through the Doctoral Program on *Hadrons in Vacuum, Nuclei, and Stars* (FWF DK W1203-N16).

References

1. T. Melde, W. Plessas, and R. F. Wagenbrunn, Phys. Rev. C **72**, 015207 (2005); ibid. C **74**, 069901 (2006).

2. T. Melde, W. Plessas, and B. Sengl, Phys. Rev. C **76**, 025204 (2007).
3. B. Sengl, T. Melde, and W. Plessas, Phys. Rev. D **76**, 054008 (2007).
4. T. Melde, W. Plessas, and B. Sengl, Phys. Rev. D **77**, 114002 (2008).
5. R. Kleinhappel, Diploma Thesis, University of Graz, 2010.
6. R. Kleinhappel and W. Schweiger, in: *Dressing Hadrons* (Proceedings of the Mini-Workshop, Bled, Slovenia, 2010), ed. by B. Golli, M. Rosina, and S. Sirca, DMFA, Ljubljana (2010), p. 33; arXiv:1010.3919.
7. L.Y. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn, Phys. Rev. D **58**, 094030 (1998).
8. L.Y. Glozman, Z. Papp, W. Plessas, K. Varga, and R.F. Wagenbrunn, Phys. Rev. C **57**, 3406 (1998) .
9. T. Sato and T. S. H. Lee, Phys. Rev. C **54**, 2660 (1996).
10. H. Polinder and T. A. Rijken, Phys. Rev. C **72**, 065210 (2005); ibid. C **72**, 065211 (2005).
11. T. Melde, L. Canton, and W. Plessas, Phys. Rev. Lett. **102**, 132002 (2009).

Kvarkovska snov v močnih magnetnih poljih

Débora Peres Menezes

Universidade Federal de Santa Catarina, Departamento de Física-CFM-CP 476, Campus Universitário-Trindade, CEP 88040-900, Florianópolis-SC, Brazil

V pričujočem prispevku skušamo razumeti razne lastnosti kvarkovske snovi, kot jih opisuje model Nambuja in Jona-Lasinia v prisotnosti močnih magnetnih polj. Najprej analiziramo raznovrstne fazne diagrame. Potem raziskujemo razlike, ki nastanejo zaradi različnih vektorskih interakcij v Lagrangeovi gostoti in uporabimo izsledke za opis zvezdne snovi. Nato se ozremo na značilnosti dekonfinacije in vzpostavitve kiralne simetrije pri kemičnem potencialu nič v okviru prepletene Polyakovove verzije modela Nambuja in Jona-Lasinia. Končno proučimo lego kritične točke za različne izbire kemičnega potenciala in gostote.

Schwinger-Dysonov pristop h kvantni kromodinamiki razloži nastanek oblečenih mas kvarkov

D. Klabučar[a] in D. Kekez[b]

[a] Physics Department, Faculty of Science, Zagreb University, Bijenička c. 32, 10000 Zagreb, Croatia
[b] Rugjer Bošković Institute, Bijenička c. 54, 10000 Zagreb, Croatia

Poleg drugih uspehov Schwinger-Dysonov pristop k neperturbativni kvantni kromodinamiki razloži tudi to, zakaj so v efektivnih kvarkovih modelih oblečene mase kvarkov zelo različne od golih mas. Če pa interakcijsko jedro vsebuje tudi perturbativni delež kromodinamske interakcije, poda Schwinger-Dysonov pristop tudi znano visokoenergijsko obnašanje kvarkovih mas, tako kot jih napoveduje perturbativna kvantna kromodinamika.

Mezonski učinki pri osnovnih in resonančnih stanjih barionov

R. Kleinhappel[a], L. Canton[b], W. Plessas[a] in W. Schweiger[a]

[a] Theoretical Physics, Institute of Physics, University of Graz, Universitätsplatz 5, A-8010 Graz, Austria
[b] Istituto Nazionale di Fisica Nucleare, Via F. Marzolo 8, I-35131 Padova, Italy

Za raziskavo mezonskih učinkov pri osnovnih in resonančnih stanjih barionov smo vključili mezonske zanke v relativistični pristop s sklopljenimi kanali. Iz računov, ki so bili doslej napravljeni na hadronskem nivoju, smo dobili rezultate za oblečene mase osnovnega stanja in resonanc nukleona. S sklopitvijo na pionski kanal smo dobili tudi širine resonanc, zlasti resonance Δ. Za zdaj smo sicer izboljšali rezultate v primerjavi z računi z enim samim kanalom, vendar so razpadne širine še vedno premajhne v primerjavi z meritvami.