BLED WORKSHOPS
IN PHYSICS
VOL. 16, NO. 1
p. 4

Proceedings of the Mini-Workshop
Exploring Hadron Resonances
Bled, Slovenia, July 5 - 11, 2015

In-medium properties of the nucleon within a π-ρ-ω model*

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Abstract. In this talk, we report on a recent investigation of the transverse charge and energy-momentum densities of the nucleon in the nuclear medium, based on an in-medium modified π-ρ-ω soliton model. The results allow us to establish general features of medium modifications of the structure of nucleons bound in a nuclear medium. We briefly discuss the results of the transverse charge and energy-momentum densities.

1 Introduction

The generalized parton distributions (GPDs) provide a new aspect of the structure of the nucleon, since they contain essential information on how the constituents of the nucleon behave inside a nucleon. The energy-momentum tensor (EMT) form factors (FFs) are given by Mellin moments of certain GPDs and characterize how mass, spin, and internal forces are distributed inside a nucleon. The EMT FFs are essential quantities in understanding the internal structure of the nucleon [1–3]. Furthermore the transverse charge which is defined by a Fourier transform in the transverse plane provides a tomographic picture of how the charge densities of quarks are distributed transversely [4, 5].

2 Lagrangian of the model

We start from the in-medium modified effective chiral Lagrangian with the π, ρ, and ω meson degrees of freedom, where the nucleon arises as a topological soliton. Using the asteriks to indicate medium modified quantities, the Lagrangian has the form

$$\mathcal{L}^* = \mathcal{L}^*_\pi + \mathcal{L}^*_V + \mathcal{L}^*_{\text{kin}} + \mathcal{L}^*_{\text{WZ}}, \tag{1}$$

* Talk delivered by Ju-Hyun Jung

where the corresponding terms are expressed as

$$\mathcal{L}_{\pi}^{*} = \frac{f_{\pi}^{2}}{4}\,\mathrm{Tr}\left(\partial_0 U \partial_0 U^{\dagger}\right) - \alpha_p \frac{f_{\pi}^{2}}{4}\,\mathrm{Tr}\left(\partial_i U \partial_i U^{\dagger}\right) + \alpha_s \frac{f_{\pi}^{2} m_{\pi}^{2}}{2}\,\mathrm{Tr}\left(U - 1\right), \quad (2)$$

$$\mathcal{L}_{V}^{*} = \frac{f_{\pi}^{2}}{2}\,\mathrm{Tr}\left[D_\mu \xi \cdot \xi^{\dagger} + D_\mu \xi^{\dagger} \cdot \xi\right]^{2}, \quad (3)$$

$$\mathcal{L}_{\mathrm{kin}}^{*} = -\frac{1}{2 g_V^{2} \zeta_V}\,\mathrm{Tr}\left(F_{\mu\nu}^{2}\right), \quad (4)$$

$$\mathcal{L}_{\mathrm{WZ}}^{*} = \left(\frac{N_c}{2} g_\omega \sqrt{\zeta_\omega}\right) \omega_\mu \frac{\epsilon^{\mu\nu\alpha\beta}}{24\pi^{2}}\,\mathrm{Tr}\left\{\left(U^{\dagger}\partial_\nu U\right)\left(U^{\dagger}\partial_\alpha U\right)\left(U^{\dagger}\partial_\beta U\right)\right\}. \quad (5)$$

Here, the SU(2) chiral field is written as $U = \xi_L^{\dagger}\,\xi_R$ in unitary gauge, and the field-strength tensor and the covariant derivative are defined, respectively, as

$$F_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - i[V_\mu, V_\nu], \quad (6)$$

$$D_\mu\,\xi_{L(R)} = \partial_\mu\,\xi_{L(R)} - i\,V_\mu\,\xi_{L(R)}. \quad (7)$$

We assume the following ansätze for the pseudoscalar and vector mesons

$$U = \exp\left\{\frac{i\boldsymbol{\tau}\cdot\mathbf{r}}{r} F(r)\right\}, \quad V_\mu = \frac{g}{2}\left(\boldsymbol{\tau}\cdot\boldsymbol{\rho}_\mu + \omega_\mu\right),$$
$$\rho_0^{a} = 0, \quad \rho_i^{a} = \frac{\varepsilon_{ika} r_k}{g\sqrt{\zeta} r^{2}} G(r), \quad \omega_\mu = \omega(r)\delta_{\mu 0} \quad (8)$$

with the Pauli matrices $\boldsymbol{\tau}$ in isospin space. One can minimize the static mass functional related to the Lagrangian in Eq. (1) and find the solitonic solutions corresponding to a unit baryon number ($B = 1$). The integrand of the static mass functional corresponds to T^{00} component of the energy momentum tensor presented below. The details of the minimization procedure can be found in Ref. [6].

Using the Lagrangian in Eq. (1), one can calculate each component of the EMT as follows:

$$\begin{aligned} T^{00*}(r) = {} & \alpha_p \frac{f_\pi^{2}}{2}\left(2\frac{\sin^{2}F}{r^{2}} + F'^{2}\right) + \alpha_s f_\pi^{2} m_\pi^{2}\left(1 - \cos F\right) \\ & + \frac{2 f_\pi^{2}}{r^{2}}\left(1 - \cos F + G\right)^{2} - \zeta g^{2} f_\pi^{2} \omega^{2} \\ & + \frac{1}{2 g^{2} \zeta r^{2}}\left\{2 r^{2} G'^{2} + G^{2}\left(G + 2\right)^{2}\right\} - \frac{1}{2}\omega'^{2} \\ & + \left(\frac{3}{2} g\sqrt{\zeta}\right)\frac{1}{2\pi^{2} r^{2}}\,\omega \sin^{2} F\, F', \end{aligned} \quad (9)$$

$$T^{0i*}(\mathbf{r}, \mathbf{s}) = \frac{e^{ilm} r^{l} s^{m}}{(\mathbf{s}\times\mathbf{r})^{2}}\rho_J(r), \quad (10)$$

$$T^{ij*}(r) = s(r)\left(\frac{r^{i} r^{j}}{r^{2}} - \frac{1}{3}\delta^{ij}\right) + p(r)\,\delta^{ij}, \quad (11)$$

where

$$\rho_J^*(r) = \frac{f_\pi^2}{3\lambda}\left[\sin^2 F + 8\sin^4\frac{F}{2} - 4\sin^2\frac{F}{2}\xi_1\right] + \frac{1}{3g^2r^2\zeta\lambda}\left[(2-2\xi_1-\xi_2)G^2\right] + \frac{g\sqrt{\zeta}}{8\pi^2\lambda}\Phi\sin^2 FF' \tag{12}$$

is the angular momentum density and

$$\begin{aligned} p^*(r) &= -\frac{1}{6}\alpha_p f_\pi^2\left(F'^2 + 2\frac{\sin^2 F}{r^2}\right) - \alpha_s f_\pi^2 m_\pi^2(1-\cos F) \\ &\quad -\frac{2}{3r^2}f_\pi^2(1-\cos F + G)^2 + f_\pi^2 g^2\zeta\omega^2 \\ &\quad +\frac{1}{6g^2\zeta r^2}\left\{2r^2G'^2 + G^2(G+2)^2\right\} + \frac{1}{6}\omega'^2, \end{aligned} \tag{13}$$

$$s^*(r) = \alpha_p f_\pi^2\left(F'^2 - \frac{\sin^2 F}{r^2}\right) - \frac{2f_\pi^2}{r^2}(1-\cos F+G)^2 + \frac{1}{g^2r^2\zeta}\left\{r^2G'^2 - G^2(G+2)^2\right\} - \omega'^2 \tag{14}$$

are the pressure and the shear force distributions inside the nucleon. The moment of inertia of the rotating soliton including $1/N_c$ corrections is given by the expression

$$\lambda^* = 4\pi\int dr\left[\frac{2f_\pi^2}{3}\left(\sin^2 F + 8\sin^4\frac{F}{2} - 4\sin^2\frac{F}{2}\xi_1\right) + \frac{2}{3g^2r^2\zeta}\left\{(2-2\xi_1-\xi_2)G^2\right\} + \frac{g\sqrt{\zeta}}{4\pi^2}\Phi\sin^2 FF'\right]. \tag{15}$$

As we mentioned above, the integral of T_{00} gives the soliton mass at zero momentum transfer $t = 0$. Therefore, the $M_2(t)$ form factor is normalized by the nucleon mass as

$$M_2(0) = \frac{1}{M_N}\int_0^\infty d^3r\, T_{00}(r) = 1 \tag{16}$$

to leading order in M_N, which is equals to the soliton mass [7]. For details, we refer to Refs. [8,9]

The EMT FFs of the nucleon parametrize the nucleon matrix elements of the symmetric EMT operator as follows [2,3]:

$$\langle p'|\hat{T}_{\mu\nu}(0)|p\rangle = \bar{u}(p',s')\left[M_2(q^2)\frac{P_\mu P_\nu}{M_N} + J(q^2)\frac{i(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})q^\rho}{2M_N} \tag{17}$$

$$+d_1(q^2)\frac{q_\mu q_\nu - g_{\mu\nu}q^2}{5M_N}\right]u(p,s), \tag{18}$$

where $P = (p+p')/2$.

One can be related GPDs. In the specific case, $\xi = 0$, one has

$$A_{20}(t) = M_2(t) = \int_{-1}^{1} dx x H(x, 0, t) \ , \tag{19}$$

$$B_{20}(t) = 2J(t) - M_2(t) = \int_{-1}^{1} dx x E(x, 0, t) \ . \tag{20}$$

In the isospin symmetric approximation the proton and neutron EMT FFs are similar. Therefore we introduce the nucleon transverse EMT densities instead of considering the proton and neutron EMT densities separately. In this approximation an unpolarized nucleon transverse EMT density takes the form

$$\rho_0^{(2)}(b) = \int_0^\infty \frac{dQ}{2\pi} j_0(bQ) A_{20}\left(Q^2\right) \ . \tag{21}$$

For a polarized nucleon one has the following transverse EMT density

$$\rho_T^{(2)}(\mathbf{b}) = \rho_0^{(2)}(b) - \sin(\phi_b - \phi_S) \times \int_0^\infty \frac{Q^2 dQ}{4\pi M_N} j_1(bQ) B_{20}\left(Q^2\right) \ . \tag{22}$$

3 Results

Now let us discuss the energy-momentum form factors of the nucleons. First of all, it is necessary to notice that in the case of exact isospin symmetry the energy-momentum form factors of the protons and neutrons cannot be distinguished in free space. The same result holds for the nucleons embedded in isospin symmetric nuclear matter. The situation changes if one introduces isospin breaking effects in the mesonic sector. In the case of in-medium nucleons the isospin asymmetric nuclear environment can generate differences in EMT form factors of the nucleons even if one has isospin symmetry in the mesonic sector in free space. For simplicity we concentrate in this work on the isopin symmetric case for both, free space as well as in medium nucleons, considering an isospin symmetric nuclear environment.

The energy-momentum form factors of the nucleons as functions of t are presented in Fig. 1 for free space nucleons and in-medium nucleons at normal nuclear matter density ρ_0.

Finally, in Fig. 2 we present the transverse energy-momentum densities inside an unpolarized and polarized nucleon for the fixed value of $b_x = 0$.

Our complete results will appear in some detail elsewhere [10].

Acknowledgments

This work is supported by the Basic Science Research Program through the National Research Foundation (NRF) of Korea funded by the Korean government (Ministry of Education, Science and Technology), Grant No. 2011-0023478 (J.H.Jung and U.Yakhshiev) and Grant No. 2012004024 (H.Ch.Kim). J.-H.Jung. acknowledges also partial support by the "Fonds zur Förderung der wissenschaftlichen Forschung in Österreich via FWF DK W1203-N16."

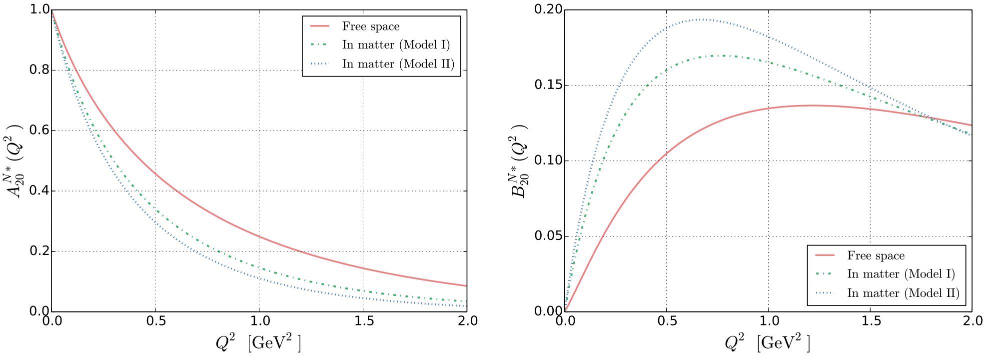

Fig. 1. The EMT form factors of the nucleon, A_{20} and B_{20}, as functions of t. The solid curve depicts the form factors in free space. The dotted and dotted-dashed ones represent, respectively, those from Model I and Model II in nuclear medium at the normal nuclear matter density ρ_0.

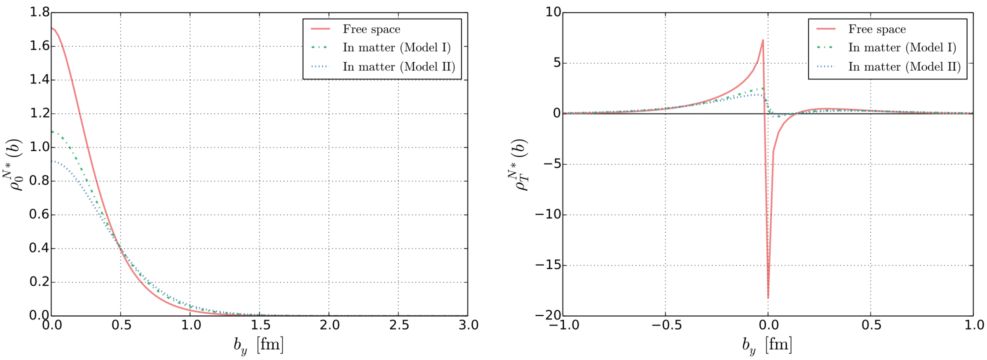

Fig. 2. Transverse energy-momentum densities inside an unpolarized and polarized nucleon with $b_x = 0$ fixed. The solid curve depicts the form factors in free space. The dotted and dotted-dashed ones represent, respectively, those from model I and model II in nuclear matter.

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Povzetki v slovenščini

Resonance in njihova razvejitvena razmerja iz perspektive časovnega razvoj

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Časovni razvoj metastabilnih stanj kaže značinosti vezanih stanj in sipanih stanj. Dinamiko teh stanj lahko opišemo s kompleksno energijo, ki ponazarja lego in širino resonance. Opisani in pojasneni so razni pristopi k temu problemu.

Lastnosti nukleona v snovi, v modelu z mezoni π, ρ in ω

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Poročamo o svežih raziskavah transverzalne gostote naboja in energije/gibalne količine pri nukleonu v jedrski snovi, osnovanih na solitonskem modelu $\pi-\rho-\omega$, prilagojenem za sistem v snovi. Rezultati nam pomagajo ugotoviti splošne lastosti takšne prilagoditve zgradbe nukleonov, vezanih v jedrsko snov. Na kratko predstavimo rezultate za transverzalno gostoto naboja in energije/gibalne količine.

ηMAID-2015: posodobitev z novimi podatki in novimi resonancami

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Predstavimo sveže podatke o fotoprodukciji η in η' na protonih, ki jih je izmerila Kolaboracija A2 na pospeševalniku MAMI. Celotni presek za fotoprodukcijo η kaže ost pri energiji praga za η'. Analizirali smo nove podatke in stare podatke (od kolaboracij GRAAL, CBELSA/TAPS in CLAS) z razvojem po pridruženih Legendreovih polinomih. Za reproduciranje novih podatkov smo uporabili izobarni model ηMAID, posodobljen s kanalom η' in novimi resonancami. Nova verzija, η MAID-2015, razmeroma dobro opiše podatke, pridobljene s fotonskimi žarki z energijami do 3.7 GeV.