Coulomb sum rule in a covariant effective quark theory[†]

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Important information on QCD effects in nuclei came from quasielastic electron scattering on nuclear targets, where a significant quenching of the Coulomb sum rule (CSR)

$$S_L(|\mathbf{q}|) = \int_{\omega^+}^{|\mathbf{q}|} \mathrm{d}\omega \frac{R_L(\omega, |\mathbf{q}|)}{Z\, G_{Ep}^2(Q^2) + N\, G_{En}^2(Q^2)},$$

compared to the non-relativistic expectation ($S_L(|\mathbf{q}|) = 1$ for $|\mathbf{q}|$ much greater than the Fermi momentum), was observed[1]; on the proviso that the nucleon form factors are not modified by the nuclear medium. (In the above expression, $R_L(\omega, |\mathbf{q}|)$ is the longitudinal response function, G_{Ep} and G_{En} are the free nucleon Sachs form factors, $Q^2 = \omega^2 + \mathbf{q}^2$ is the 4-momentum transfer, and ω^+ excludes the elastic peak.)

In this work we extend our description of the free nucleon form factors[2], which were obtained by using the Nambu-Jona-Lasinio (NJL) model as an effective quark theory of QCD, to the in-medium case, including the self consistent scalar and vector potentials in the nucleon propagators. As a result, we find that at nuclear matter saturation density the proton Dirac and charge radii each increase by about 8%. Using these in-medium nucleon form factors and propagators obtained in the effective quark theory, we calculate the quasi-elastic longitudinal response function in nuclear matter by solving the Dyson equation for the polarization propagator in the relativistic random phase approximation (RPA)[3] on the level of nucleons. For the nucleon-nucleon interaction we take into account the exchange of σ, ω and ρ mesons, described in the framework of the NJL model.

Our Hartree and RPA results for the longitudinal response function are shown in Fig. 1 for $|\mathbf{q}| = 0.5$ and 0.8 GeV. We find that the longitudinal response function determined with in-medium nucleon form factors is quenched relative to the result obtained using the free form factors. In our calculation, this quenching is directly associated with a softer proton Dirac form factor (F_{1p}) in the medium. We observe a qualitative agreement with the ^{208}Pb data of Ref. 1.

Results for the CSR, using the nucleon form factors evaluated at three baryon densities ($\rho_B = 0,\ 0.1,\ 0.16\,\mathrm{fm}^{-3}$) are presented in Fig.2. At $|\mathbf{q}| \simeq 1$ GeV we find relativistic corrections of about 20% (relative to the nonrelativistic value $S_L = 1$), and an additional 30% reduction by the nuclear medium for the case $\rho_B = 0.16\,\mathrm{fm}^{-3}$. We observe a qualitative agreement with the ^{208}Pb data, but not with the state-of-the-art Green function Monte Carlo (GFMC) result for ^{12}C from Ref. 4. The ^{12}C data from Ref. 5 shown in the figure still cannot distinguish between our and the GFMC results.

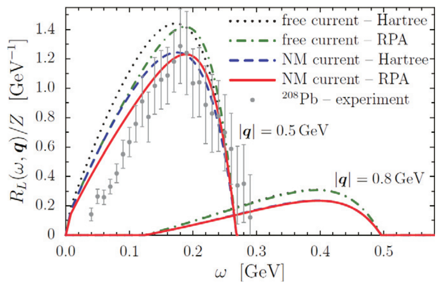

Fig. 1. Hartree and RPA results for the longitudinal response function in symmetric nuclear matter. Results labeled *free current* are obtained using the free nucleon form factors, whereas the *NM current* results use the in-medium form factors. The ^{208}Pb data at $|\mathbf{q}| = 0.5$ GeV are also shown for comparison.

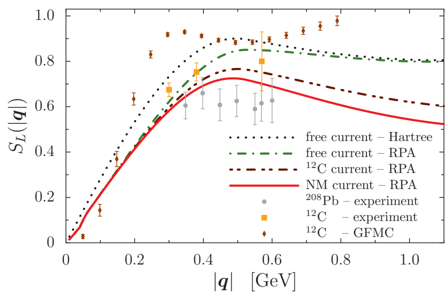

Fig. 2. CSR determined using the nucleon form factors at baryon density $\rho_B = 0$ (*free current*), $\rho_B = 0.1\,\mathrm{fm}^{-3}$ (typical of ^{12}C), and $\rho_B = 0.16\,\mathrm{fm}^{-3}$ (*NM current*). The ^{208}Pb and ^{12}C data as well as the Green Function Monte Carlo (GFMC) results from Ref. 4 are also shown for comparison.

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References

1) J. Morgenstern and Z. Meziani, Phys. Lett. **B 515**, 269 (2001).
2) I.C. Cloët, W. Bentz and A.W. Thomas, Phys. Rev. **C90**, 045202 (2014).
3) K. Wehrberger, Phys. Rept. **225**, 273 (1993).
4) A. Lovato et al., Phys. Rev. Lett. **111**, 092501 (2013).
5) P. Barreau et al., Nucl. Phys. **A 402**, 515 (1983).

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