Essay

EMC Effect in Nuclear String Model

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Abstract

CLAS Collaboration has published an interesting work relating to EMC effect. The conclusion of the research group is that the formation of correlated nucleon pairs leads to the observed surprisigly strong modification of quark structure functions inside nucleon. The TGD based proposal based on nuclear string model is somewhat different. Formation of di-nucleons would occur as the nuclear flux tube touches itself. This implies a de-localization of quark color to the volume of di-nucleon formed by color confinement. Di-nucleons would consist of 3 di-quarks forming anti-color triplets and also meson-like quark pair is needed. The longitudinal momenta of quarks inside di-quark would be same and this constraint would reduce degrees of freedom. The distribution functions for the longitudinal momentum fraction of di-quark could be same as that for quarks.

1 Introduction

I received from Wes Johnson a a link (`http://tinyurl.com/s939nrb`) to a popular article about the recent work by CLAS collaboration related to EMC effect. See also Wikipedia article (`http://tinyurl.com/rg5wwux`) and second popular article (`http://tinyurl.com/y44anveb`). The popular articles refer to the publication of CLAS Collaboration relating to EMC effect [1] (`http://tinyurl.com/thspz2n`). The conclusion of the research group is that the formation of correlated nucleon pairs leads to the observed surprisigly strong modification of quark structure functions insided nucleon.

Since deep inelastic scattering (DIS) occurs for large momentum exchanges (few GeV) and nuclear physics energy scale (few MeV) is much lower, one would expect that the nucleus behaves as a collection of free nucleons in DIS. Therefore EMC effect was a surprise. The distribution for longitudinal momenta of quarks inside nucleons inside nuclei deduced from the experiments seemed to differ dramatically from that for free nucleons. Nuclear binding would have large effect on quark behavior.

Very roughly, the ratio for the probabilities $f_{Fe}(x)$ and $f_D(x)$ of quark to have momentum fraction x in Fe and D is not constant equal to 1 as expected (and thus independent on the size of nucleus) but decreases almost linearly for x in range .3-.7. In heavier nuclei large longitudinal momentum fractions seem to be less probable. Somehow the quarks would be slowed down and small values of x would become more favored. The effect becomes stronger in heavier nuclei as the figure 1 of the Wikipedia article (`http://tinyurl.com/rg5wwux`) comparing the effect for D and Fe demonstrates.

The model of CLAS group assumes that there are strong short range correlations between nucleons in nuclei. About 20 per cent of nucleons would have these correlations at given moment of time. One might say that they are stuck together. The TGD based proposal based on nuclear string model is somewhat different. Formation of di-nucleons would occur as the nuclear flux tube touches itself. This implies a de-localization of quark color to the volume of di-nucleon formed by color confinement. Di-nucleons would consist of 3 di-quarks forming anti-color triplets and also meson-like quark pair is needed. The longitudinal momenta of quarks inside di-quark would be same and this constraint would reduces degrees of freedom. The distribution functions for the longitudinal momentum fraction of di-quark could be same as that for quarks.

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2 TGD based model

The description of nuclei as nuclear strings is rather old part of TGD and EMC effect give hopes of testing this model.

2.1 Nuclear string model

In TGD nuclei are assumed to be nuclear strings [4] (`http://tinyurl.com/rc4umgv`).

1. The 10 year old nuclear physics anomaly [2, 3] meaning that the abundances in solar core seems to be higher than those at the surface of Sun and outside it in meteors led to a more detailed view about nuclear string model. TGD based model for "cold fusion" assumes nuclear strings consisting of nucleons at magnetic flux tubes can be dark in the sense that nucleons have effective Planck constant $h_{eff} = nh_0 > h$. The Compton length of nucleon would be essentially electron Compton length. Pollack effect would lead to formation of dark nuclei which then decay to ordinary ones liberating essentially all nuclear binding energy. Hot fusion would involve transformation of ordinary nuclei to dark nuclei as counterpart of tunneling and the resulting dark reaction products would decay to ordinary nuclei [5] (`http://tinyurl.com/yyjy5e2r`).

2. This picture in turn led to a view about stellar interiors as dark nuclear flux tube tangles. Blackhole would correspond to a volume filling flux tube spaghetti for which the flux tube corresponds to $h_{eff} = h$ and has radius given by nucleon Compton length. One can consider the possibility that other asymptotic states of stars correspond to blackhole like spaghettis but having $h_{eff} > h$ and larger flux tube radius.

The idea that also ordinary nuclei are similar flux tube spaghetti is attractive. The flux tube need not be volume filling but it could touch itself and these touchings could correspond to the formation of nucleon pairs suggested by the experimental findings [1]. Consider first nuclear string model.

1. Nucleons would be along magnetic flux tube like pearls in necklace.

2. The additional assumption is that two sub-sequent nucleons are connected by meson-like quark-antiquark pair having mass in MeV range - nuclear binding energy scale - rather than that of virtual pion about 140 MeV- p-adically scaled down pion. The motions of neighboring nucleons along the nuclear necklace would be strongly correlated: they would form correlated pairs but this need not affect the momentum distributions of quarks inside nucleons. These mesonlike flux tubes would be by Uncertainty Principle loops of order Compton length of light quark and would have no appreciable role in DIS since it would occur in the length scale of nucleon

3. One can consider two options for the meson like bonds between nucleons but neither is relevant for the model to be discused in the following.

   (a) The loop-like bonds are non-colored meson-like entities. The quark distributions inside nucleons would not be affected appreciably. DIS would take place from quarks of single nucleon. Bonds would have no appreciable effect on DIS so that this option fails.

   (b) The loop-like bonds between nucleons could be also colored. Also nucleons would be colored if di-nucleon would is color neutral. The point would be that color confinement would bind nucleons very strongly to single di-nucleons unlike in previous case and DIS would take place from quarks of di-nucleon rather than those of nucleon. The x-distributions of quarks inside colored nucleons *could but need not* differ from those for free nucleons. Only color confinement forming di-nucleon would matter.

2.2 Trying to understand EMC effect in TGD framework

What could happen in EMC effect.

1. The hypothesis is that the self-contacts of the flux tube in nuclear spaghetti would give rise to a formation of di-nucleons. Quark color is de-localized to the volume of di-nucleon formed by color confinement. There would be no EMC effect for D since it cannot have transversal self-contacts: this is observed. The probability of self-touchings increases with the atomic number A and increases with the local density of the nucleons: also this has been observed.

2. In self-contact di-nucleon {pp, pn, pn, np} is formed as color-confined 6-quark state. The observation that the tensor product $3 \otimes 3$ of two color triplets contains color anti-triplet $\overline{3}$ and 6-plet suggests what could happen. Assume that the di-nucleon state is color singlet analogous to anti-nucleon in the sense that it is color singlet formed from 3 di-quarks (uu,ud,du,dd) in color anti-triplet state $\overline{3}$. Di-quarks are bosons and their wave functions be antisymmetric with respect to the exchange of quarks. Spatial wave function is symmetric so that also spin wave function must be symmetric. Spin 1 states would be in question. The magnetic moment of di-quark is proportional to $\overline{S}/2m_n$ and classically the same as that of quark so that the magnetic interaction of di-quark with the virtual photon in DIS should be nearly the same as that of quark.

3. The formation of di-quark state forces the values of longitudinal momentum fractions x_i of quarks to be same: $x_1 = x_2 = x$. Since the mass is doubled, the longitudinal momentum fraction of di-quark is same as that of quark: $x_D = x$. A stronger assumption is that di-quark distribution function $f_D(x)$ is same as quark distribution function: $f_D(x) = f(x)$.

The rate for DIS from nucleon is proportional to the sum $K = \sum_i Q_i^2$, where Q_i are quark charges. For proton one obtains $K(p) = 4/9 + 4/9 + 1/9 = 1$ and for neutron $K(n) = 4/9 + 1/9 + 1/9 = 2/3$. The behavior of the the ratio of the form factor for heavier nuclei requires that the effective value of K for single nucleon deduced as the average of di-nucleon parameters $K(N_1N_2)$ for di-nucleons N_1N_2 is smaller than the average value for single nucleon states. Does this require conditions on allowed em charges of di-nucleons N_1N_2?

To proceed one must test various working hypothesis by comparing them with the qualitative behavior of the form factor F_2 displayed in the Wikipedia article.

2.2.1 Models without meson-like quark pairs

Assuming that the formation of contact does not involve creation of $q\overline{q}$ pair, one can consider two options :

Option 1: Allow all charge states for di-quarks.
Option 2: Allow only charge states for which K is minimum.

1. For di-nucleon pp$_1$ = (uud)(uud) = (uu)(ud)(ud) one obtains $K(pp_1) = 16/9 + 1/9 + 1/9 = 2 = 2K(p)$. For di-nucleon pp$_2$= (uu)(uu)(dd) one obtains $K(pp_2) = 36/9 > 3K(p)$. The average is $\langle K(pp)\rangle = (K(pp_1) + K(pp_2)/2 = (36 + 18)/18 = 3$.

   If one thinks di-nucleon effectively as two ordinary nucleons as done in experiment, one has $K(pp, eff) = 3/2 > 1 = K(p)$ for **Option 1**). Allowing only the state (uu)(ud)(ud) minimizing K (**Option 2**) one has $K_{eff}(pp) = 1 = K(p)$.

2. $nn_1 = (udd)(udd) = (ud)(ud)(dd)$ gives $K(nn_1) = 6/9$. $nn_2 = (uu)(dd)(dd) = (16+4+4)/9 = 24/9$. The average is $\langle K(nn)\rangle = 12/9$ giving $K_{eff}(nn) = 2/3 = K(n)$ for **Option 1**.

   Allowing only the state (ud)(ud)(dd) **Option 2** one has $K(nn, eff) = 1/3 < K(n)$.

3. For pn_1 = (uud) (udd)= (ud)(ud)(ud) one has $K(pn_1) = 1/3 < 2/3 = K(n)$. For pn_2= (uu)(ud)(dd) one has $K(pn_2) = 21/9 > K(p)$. The average is $\langle K(pn) \rangle = 8/3$ and $K(pn, eff) = 4/3 > K(p)$ **Option 1**.

   Allowing only state (ud)(ud)(ud) **Option 2** one has $K_{eff}(pn) = 1/3 < K(n)$.

The average of $K_{eff} = (K_{eff}(pp) + K_{eff}(nn) + 2K_{eff}(pn)/4 = 11/8$ to be compared with the average $K_{st} = (K(p) + K(n))/2 = 5/6$. **Option 1** is therefore not consistent with the observations.

For **Option 2** the average over the $N_1N_2 \in \{pp, nn, pn, np\}$ is $K_{eff} = 7/12$ to be compared with $K_{st} = 5/6$. One has $K_{eff}/K_{st} = 42/60 = 7/10$. Assuming that fraction $p = 1/5$ of nucleons are paired by contacts one obtains for **Option 2** $K_1 = (1 - p) \times K_{st} + p \times K_{eff} = 47/60$ to be compared with $K_{st} = 50/60$. The ratio $K_{eff}/K_{st} = 47/50$ is 6 per cent smaller than unit whereas 10 per cent is suggested by Fig. 1 of Wikipedia article.

2.2.2 Model with di-quarks and quark pair

A more complex model assumes the presence of quark pair $q\overline{q}$ in the contact and minimization of K by a suitable choice of di-quarks q_iq_j and $q_1\overline{q}_2$ pairing.

1. $p(d\overline{d})p = (ud)(ud)(ud)(u\overline{d})$ gives $K_{eff} = 2/3$.
2. $n(u\overline{u})n = (ud)(ud)(ud)(d\overline{u})$ gives $K_{eff} = 2/3$.
3. $p(u\overline{u})n = (uud)(u\overline{u})(udd) = (ud)(ud)(ud)(u\overline{u})$ gives $K_{eff} = 1/3$.

The average value of K_{eff} over four pairs {uu,dd,ud,du} is $\langle K_{eff} \rangle = 1/2$. For $p = 1/5$ this gives $K_1 = (1 - p)K + pK_{eff} = 23/30$. K_1/K_{st} deviates by 8 per cent from unity. This is consistent with the result of the figure 1 of the Wikipedia article (`http://tinyurl.com/rg5wwux`).

This model resembles the earlier nuclear string model but could be criticized for being too complex. Second criticism concerns scales. Di-quarks and meson-like quark pair should behave like point-like particles in the GeV scale of DIS. Di-quarks should therefore have size scale not much larger than that of quark. Nucleons would reside along $k = 107$ flux tube with nucleon Compton radius as radius. The experimental data on EMC suggest that the nucleons are larger than normally by about 10-20 per cent. This could be average for the sizes of ordinary nucleon and 2 times larger di-nucleon: one would have $(1 - p) + 2p = 6/5$ and 20 per cent increase in effective nucleon size.

Could the notion of many-sheeted space-time allow to associate di-nucleons with space-time sheet with p-adic length scale $L_p \propto \sqrt{p} = L(k) = 2^{k/2}$ (by p-adic length scale physics one has $p \simeq 2^k$). One would have $k = 109$ (prime). I have proposed earlier that deuteron could correspond to $k = 109$ space-time sheet. Deuteron cannot be however regarded as $n(u\overline{u})n$ state since one would have $K_{eff} = 2/3$ instead of $K = 5/6$. Could one regard di-nucleons as states with $k = 107$ but $h_{eff} = 2h$ so that the radius would correspond to $k = 109$? Touching is indeed critical phenomenon and h_{eff} can increase at criticality.

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