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Shear forces and tensor polarization

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The forward matrix elements of energy momentum-tensor proportional to tensor polarization are related to average shear force in hadron. It is zero when summed over quarks and gluons due to equivalence principle. There is an evidence for its validity separately for quarks and gluons in deuteron, manifesting the extension of the equivalence principle. The experimental tests may be performed in DIS and other hard processes, like high p_T hadrons production. The shear viscosity for hadrons and its relation with exotic hybrid mesons production is discussed

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1. Introduction

The recent experimental investigation [1] of the pressure in proton attracted attention to the studies of the forces acting to the partons in hadrons [2, 3, 4] and photons [5, 6]. The special role hear is played by the the dispersion relations for Deeply Virtual Compton Scattering (DVCS) amplitude [7, 8] resulting, at the leading order, in the "holographic" sum rule [7]. The gravitational form factors [9], related to pressure, may be also considered in the time-like region, and this opportunity was recently explored to get the relevant information for pion [10].

The shear forces provide the natural counterpart to the pressure and appear in the same model [2, 3], corresponding to the spherically symmetric distribution of matter. At the same time, they are also manifested in the inclusive processes with tensor polarized spin-1 particles.

Here we address this problem and find the evidences in favour of the average shear force to be compatible to zero separately for quarks and gluons which may be considered as an extension of equivalence principle. We also discuss the possible imnplementation of the notion of shear viscosity for both GPD and GDA channels.

2. Shear forces and tensor polarization

The structure of spin -1 particle energy momentum tensor matrix elements is quite rich [11]. The natural way to get the traceless part of energy-momentum tensor *forward* matrix element is provided by tensor polarisation, as the relevant tensor $S^{\mu\nu}$ is a traceless one by construction. The contribution of the "tensor polarized" parton distribution C_T (introduced as an "aligned" one [12]) is constrained by the zero sum rule [12], which may be decomposed to quark and gluon components [13]:

$$\sum_q \int_0^1 C_i^T(x)xdx = \delta_T(\mu^2), \tag{2.1}$$

$$\int_0^1 C_G^T(x)xdx = -\delta_T(\mu^2). \tag{2.2}$$

As a result, the matrix elements of energy momentum tensors of quarks and gluons look like

$$\sum_q \langle P,S|T_i^{\mu\nu}|P,S\rangle_{\mu^2} = 2P^\mu P^\nu(1-\delta(\mu^2)) + 2M^2 S^{\mu\nu}\delta_T(\mu^2) \tag{2.3}$$

$$\langle P,S|T_g^{\mu\nu}|P,S\rangle_{\mu^2} = 2P^\mu P^\nu\delta(\mu^2) - 2M^2 S^{\mu\nu}\delta_T(\mu^2), \tag{2.4}$$

where the second terms describe the average (integrated over transverse distance) shear force.

The zero sum rules (2.1) were later interpreted [14] as yet another manifestation of Equivalence Principle (EP), as it was done earlier [15] for Ji sum rules. In turn, the smallness of δ_T, compatible with the existing HERMES data, was suggested [14] to be the new manifestation of Extended Equivalence Principle (ExEP) [16, 17, 9] valid separately for quarks and gluons in non-perturbative QCD due to the confinement and chiral symmetry violation. It was originally suggested for anomalous gravitomagnetic moments [16, 9]. In particular, it provides the rotation of spin in the terrestrial experiment with the angular velocity of Earth rotation. Let us stress, that it may seem trivial if spin is considered just as a vector. However, it became highly non-trivial if the measurement of spin by the device rotating together with Earth is taken into account. This is a particular example of the practical importance of the quantum theory of measurement. Another example may be represented by the Unruh radiation in heavy-ion collisions [18], which implies that the particles production may be also considered as a quantum-mechanical measurement in the non-inertial hadronic medium.

Recently, ExEP was also discovered for the pressure [19].

To check ExEP for shear force one may use future studies of DIS at JLab and of Drell-Yan process with tensor polarized deuterons [20]. This opportunity, in addition to KEK, may be provided by the NICA collider ar JINR [21] [1] .

Note that tensor polarised parton distribution may be also measured in *any* hard process with the relevant combination of deuteron polarisations, in particular, for large p_T pions production, providing much better statistics. The correspondent quantity can be the P-even Single Spin asymmetry

$$A_T = \frac{d\sigma(+) + d\sigma(-) - 2d\sigma(0)}{d\sigma(+) + d\sigma(-) + d\sigma(0)}, \tag{2.5}$$

where the differential cross-section with definite polarisation of deuteron appear.

Note that due to the tensor polarisation tensor being traceless the sum rule for the three mutually orthogonal orientations of coordinate frame is valid [12]:

$$\sum_i S^i_{zz} = 0. \tag{2.6}$$

As a result, the leading twist kinematically dominant "longitudinal" tensor polarization can be obtained by accelerating the *transverse* polarized deuterons which will be accessible at NICA.

3. Shear forces and GDAs

The gravitational form factors [9], related to pressure, may be also considered in the time-like region, and this opportunity was recently explored in the exclusive production of pion pairs in the collisions if real and virtual photons to get the relevant information for pion [10].

It will be very interesting to extend this analysis for the production of $\pi\eta$ pairs with exotic quantum numbers $J^{PC} = 1^{-+}$, being the natural generalization of the production of exotic hybrid mesons [22].

The relevant matrix element of the quark symmetrized energy-momentum tensor

$$\langle \pi\eta(P,\Delta)|T_i^{\alpha\nu}|0\rangle_{\mu^2} = \eta_i(\mu^2)P^\alpha\Delta^\nu \tag{3.1}$$

may be considered as a sort of *shear viscosity*). Indeed, the relative momentum of the pair (being the counterpart of hybrid meson polarization vector) may be considered after crossing $P \leftrightarrow \Delta$ to GPD channel as corresponding to (average) velocity $v^\nu \sim P^\nu/M$ while the total momentum of the pair should correspond to (transverse) derivative in the viscosity tensor.

The viscosity interpretation in the GPD channel itself should naturally correspond to the appearance of transition GPDs, (naive) T-oddness and imaginary phases. The possible smallness of relevant matrix element might be related to famous holographic bound for viscosity.

[1] Complementary probes are provided by vector mesons [17].

Needless to say, that the total average viscosity of quarks and gluons should be zero, which is a natural generalization of nullification of exotic hybrid meson coupling [22, 23]

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4. Conclusions

The tensor polarization of spin 1 hadrons is related to shear forces. The available HERMES data are compatible with Extended Equivalence Principle valid separately for quarks and gluons. The latter may provide the gravity-proof confinement [9] even at extremely large gravitational fields. The more precise data may be obtained in hadronic P-even SSA at NICA. The studies of GDA related to hybrid exotic mesons may provide the link to analog of shear viscosity for hadrons.

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