Covariant calculation of quark distribution functions in ρ^+-meson†

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Spin-1 hadrons are characterized by three elastic form factors (FFs) and four leading-twist parton distribution functions (PDFs). As compared to the familiar spin-1/2 case, the new functions for the spin-1 case are the quadrupole FF and the tensor polarized PDF, both carrying important information on the orbital motion of the constituents. Recent calculations[1] have shown that the quadrupole form factor of the ρ^+ meson is of opposite sign compared to the deuteron. It is then of interest to compare their tensor polarized PDFs as well.

In this work we use the Nambu-Jona-Lasinio (NJL) model as an effective quark theory of QCD to calculate the nine T-even transverse momentum-dependent quark distribution functions (TMDs) of the ρ^+ meson in a completely covariant way. Important effects of quark confinement are included via the use of the proper-time regularization scheme, which avoids unphysical thresholds for the decay of hadrons into free quarks. Integration of the TMDs over the transverse quark momentum components leaves the four PDFs, namely the unpolarized $f(x)$, helicity $g(x)$, transversity $h(x)$, and tensor polarized $f_{LL}(x)$ distribution functions.[2] Our results for these four PDFs are shown in Fig. 1 at the model scale of $Q_0^2 = 0.16$ GeV^2, and in Fig. 2 at the scale $Q^2 = 5$ GeV^2.

Our function $f_{LL}(x)$ is related to the function $b_1(x)$ of Ref. 4) by $b_1(x) = \frac{1}{2} f_{LL}(x)$, and its partonic interpretation at the model scale can be expressed as

$$f_{LL}(x) = q^{(0)}(x) - \frac{1}{2}\left(q^{(1)}(x) + q^{(-1)}(x)\right) ,$$

where $q^{(\lambda)}(x) = q^{(\lambda)}_{\uparrow} + q^{(\lambda)}_{\downarrow}(x)$ is the unpolarized valence quark distribution in a longitudinally polarized ρ^+ meson with spin projection $\lambda = 0$ and $\lambda = \pm 1$. Accordingly, the function $f_{LL}(x)$ satisfies the sum rules

$$\int_0^1 \mathrm{d}x\, f_{LL}(x) = \int_0^1 x\,\mathrm{d}x\, f_{LL}(x) = 0 ,$$

which simply mean that the valence quark number and momentum are independent of the hadron's spin state. Our result for the spin sum at the model scale is

$$\int_0^1 \mathrm{d}x\, g(x) = 0.56.$$

This means that the total valence quark and antiquark contribution to the spin of the ρ meson is 56%,

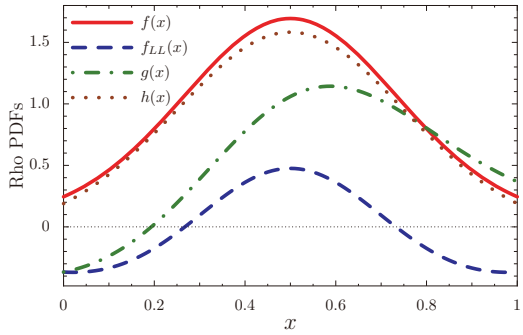

Fig. 1. The unpolarized ($f(x)$), helicity ($g(x)$), transversity ($h(x)$) and tensor polarized ($f_{LL}(x)$) PDFs of the ρ^+ meson at the model scale $Q_0^2 = 0.16$ GeV^2.

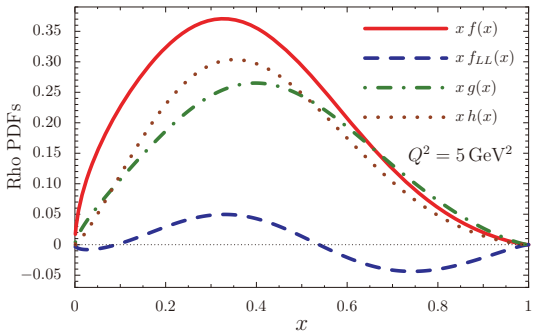

Fig. 2. The four PDFs of the ρ^+ meson, multiplied by x, at the scale $Q^2 = 5$ GeV^2. The NLO non-singlet DGLAP evolution was performed[3] to evolve the PDFs of Fig. 1 from 0.16 GeV^2 to 5 GeV^2.

which implies a substantial contribution of 44% from the quark orbital angular momentum. Our result for the tensor charge is $\int_0^1 \mathrm{d}x\, h(x) = 0.94$, which is close to the naive quark model expectation of unity.

In a qualitative comparison between our tensor polarized PDF of the ρ^+ meson and the HERMES Collaboration data for the deuteron[5] we find a similar behavior as functions of x, but the overall sign is opposite and the magnitude is larger for the case of the ρ^+ meson by roughly one order.

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