Tomography of the light mesons

Satvir Kaur[1*] and Harleen Dahiya[2]
Department of Physics, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar-144011, INDIA

Our aim is to study the complex internal structure of the spin-0 hadrons (pion and kaon) and the spin-1 hadron (ρ-meson) using the light-front (LF) nonperturbative methods, which inscribe the hadron properties. The modelled hadronic light-front wave functions (LFWFs) for the light pseudoscalar mesons and the light vector mesons are used, which are extracted using the holographic Schrödinger equation and the ordinary Schrödinger equation. In literature, the two models are referred to as: (i) light-front holographic model, and (ii) light-front quark model. The model scales, which are taken into account for the pseudoscalar mesons are, $\mu_{\rm LFH} = 0.316$ GeV and $\mu_{\rm LFQM} = 0.490$ GeV. Meanwhile, for the vector mesons, these are $\mu_{\rm LFH} = 0.447$ GeV and $\mu_{\rm LFQM} = 0.436$ GeV. The subscripts LFH and LFQM denote the light-front holography and the light-front quark model respectively. The modelled LFWFs are expected to be defined at these scales and the observables predicted using these models have been presented below.

The direct interaction of photon with electrically charged quark provide information about the hadron structure through the radiative form factors, which depend on the momentum transfer $q^2(=-Q^2)$. These form factors can be "static" or "dynamic". Our main focus is to study the "dynamic"/transition form factors for the light vector to pseudoscalar mesons. In particular, we have studied the timelike transition form factors at zero (related to the decay widths) or low momentum transfer: $\omega \to \pi\gamma^{(*)}$, $\phi \to \pi\gamma^{(*)}$, $\phi \to \eta\gamma^{(*)}$ in the LF holographic model. We have also studied the $K^* \to K\gamma^{(*)}$ decay in the spacelike region and have found a zero coming w.r.t. Q^2 particularly in the charged decay. This is because of the destructive interference between the photon-quark and photon-antiquark coupling terms. Apart from the decays mentioned above, a few additional decays have been studied by calculating their decay widths. Our predictions with the spin-improved holographic wavefunctions are found to be in excellent agreement with the available experimental data for the form factors and the decay widths.

We have further investigated the valence quark parton distribution amplitudes (PDAs) and the parton distribution functions (PDFs) of the light spin-0 mesons, specifically the pion and the kaon, in the LF quark model. We have performed a leading order (LO) QCD evolution on PDAs using Efremov-Radyushkin-Brodsky-Lepage (ERBL) equations to the scale $\mu = 3.16$ GeV, which is relevant to the available experimental data. The pion PDAs have been found to be in agreement with the experimental data i.e. E791 data [1] and close to the asymptotic result. On the other hand, for the case of kaon, the behavior of the valence quark PDA differs from the asymptotic result which is due to the presence of unequal valence quark masses in the kaon. Further, we have investigated the only non-zero pion PDF(x), f_1, in the LF quark model and LF holographic model [2] at the model scales. After QCD evolution of the pion unpolarized PDF from the LF quark model scale $\mu^2_{\rm LFQM} = 0.246$ GeV^2 to the scale $\mu^2 = 16$ GeV^2, it has been compared with the LF holographic model [2], BLFQ predictions [3] and the E615 data [4, 5]. Our results are in agreement with the modified E615 data. Apart from this, we have studied the valence quark transverse momentum-dependent parton distributions (TMDs$(x, \mathbf{k}^2_\perp)$), where $\mathbf{k}_\perp$ is the quark

*Electronic address: satvirkaur578gmail.com

transverse momentum, for the case of pion and kaon. We have found one T-even TMD, f_1 (also known as unpolarized TMD), and one T-odd TMD, $h_1^\perp$ (Boer-Mulder's TMD), in the case of pion and kaon. We have performed the evolution of the unpolarized quark TMD for the case of pion. An increase in width and decrease in the magnitude of the distribution peak is observed while increasing energy scale μ^2. Finally, we have considered generalized parton distributions (GPDs$(x, \zeta, t = -\mathbf{q}_\perp^2)$), evaluated for zero skewness $\zeta = 0$, in the DGLAP region, $0 < x < 1$. Both chiral-odd and chiral-even GPDs, $H(x, 0, t)$ and $E_T(x, 0, t)$, are taken into consideration. At zero momentum transfer, $\mathbf{q}_\perp = 0$, the chiral-even GPD lead to the unpolarized quark distribution, $H(x, 0, 0) = f_1(x)$.

Furthermore, we have explored the case of light spin-1 hadron, in particular the ρ-meson. We have used the LF holographic model and the LF quark model to evaluate various distributions for the case of ρ-meson. First of all, we have focused on the PDAs by considering longitudinally polarized ρ-meson. Our evolved PDAs are close to the asymptotic result. Secondly, the four non-zero T-even PDFs, namely, the unpolarized distribution f_1, the helicity distribution g_1, the transversity distribution h_1 and the tensor polarized distribution f_{1LL} have been explored. The tensor polarized PDF, which is different from ordinary PDFs, is zero in the LF quark model. As in the case of the pion, we have applied QCD evolution to the ρ-meson PDFs as well and a similar qualitative behavior of all the PDFs with the available theoretical predictions in NJL model has been observed. Proceeding further, the 3D imagining of the ρ-meson in the momentum space has been explored using the LF holographic model and the LF quark model. The ρ-meson can provide information on 9 T-even TMDs. We have 8 non-zero TMDs in the LF holographic model whereas 6 non-zero TMDs in the LF quark model. The tensor polarized spin-1 TMDs: f_{1LL}, f_{1LT} and f_{1TT}, are absent in the LF quark model because of a different spin structure from the LF holographic model. However, the ordinary TMDs, f_1, g_{1L}, g_{1T}, h_1 and $h_{1L}^\perp$ have been observed to provide quite similar behavior in both the models. Our findings of the valence quark TMDs have been found to be consistent with the NJL model results [6] and also satisfy all the positivity conditions. Further, the first two $\mathbf{k}_\perp$ moments have been observed in the LF models, and compared with the previous findings in NJL model [6]. We have also examined the quark spin densities of the ρ-meson in the transverse momentum plane which depend on different polarization configurations. When both the quark and the ρ-meson are longitudinally or transversely polarized, axially symmetric distribution has been observed in the transverse momentum plane. However, the effect of spin generates dipolar distortion when the quark is polarized along longitudinal/transverse direction and ρ-meson is polarized along transverse/longitudinal direction. TMDs and the PDFs may help the experimental groups to measure these distributions for the ρ-meson. The results presented in this study alongwith other theoretical predictions on the TMDs and the PDFs may help the experimental groups to measure these distribution which will provide deeper insight on the internal structure of the ρ-meson.

To conclude, we have found an excellent agreement of our holographic and LF quark model predictions with the experimental data available for the various light vector to pseudoscalar radiative transition form factors, the valence quark PDAs and PDFs of the pion.

References

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